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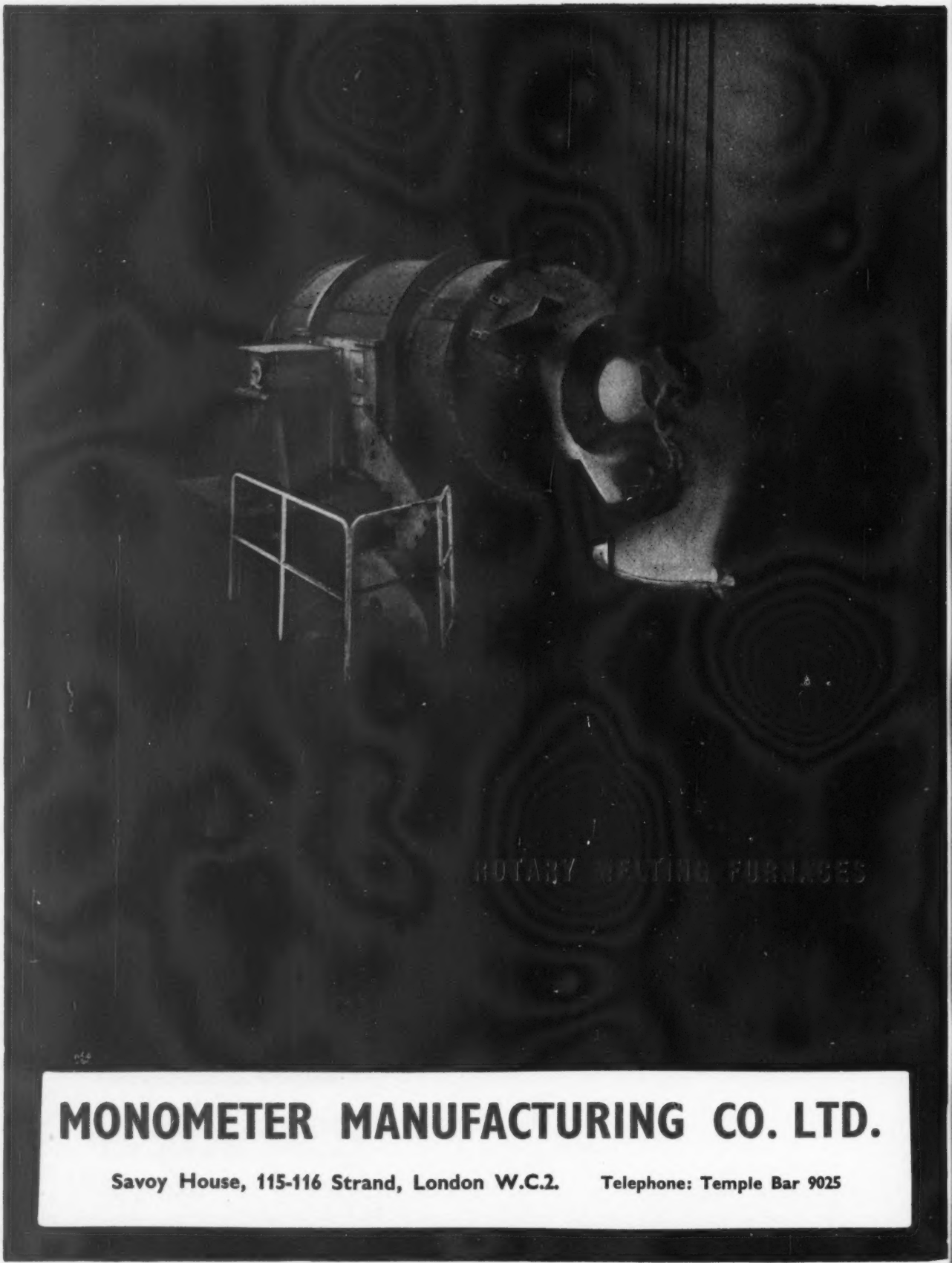

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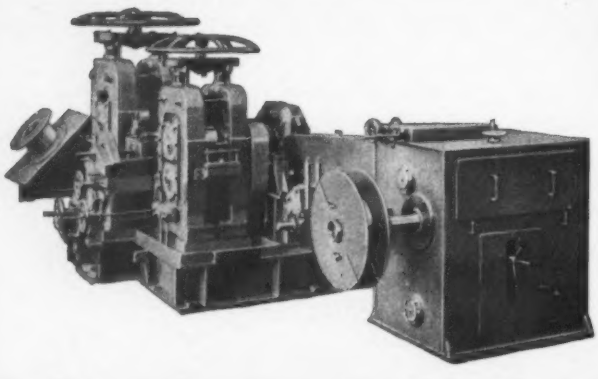

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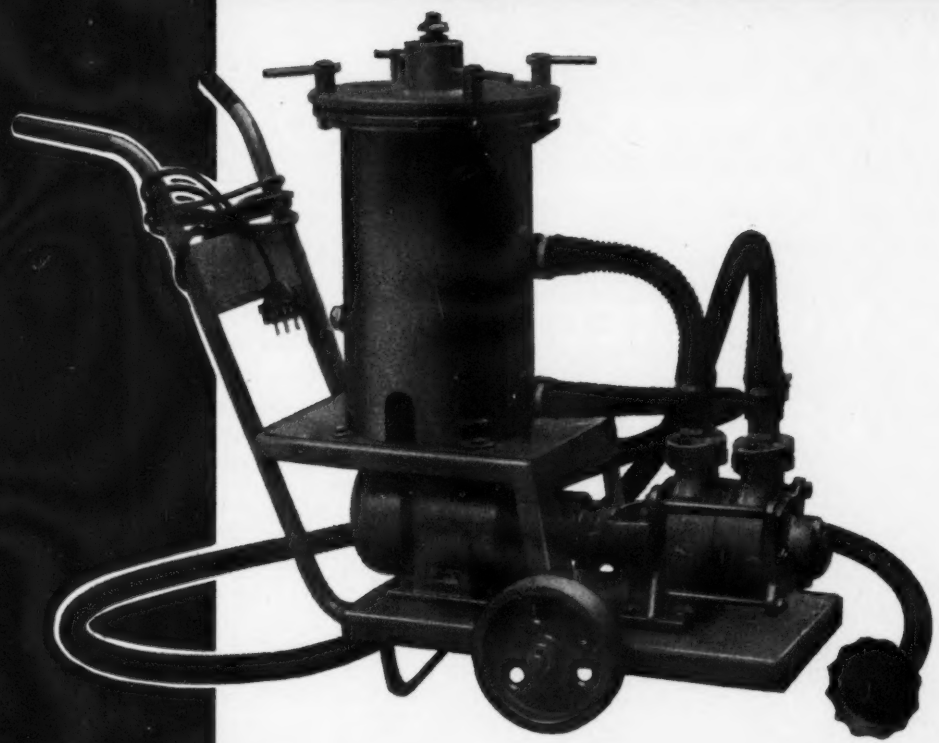

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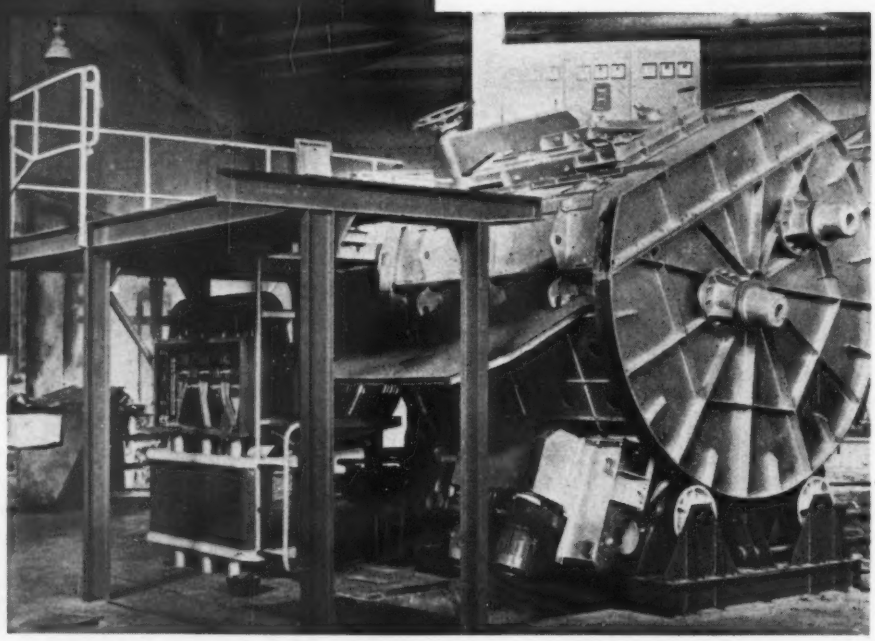

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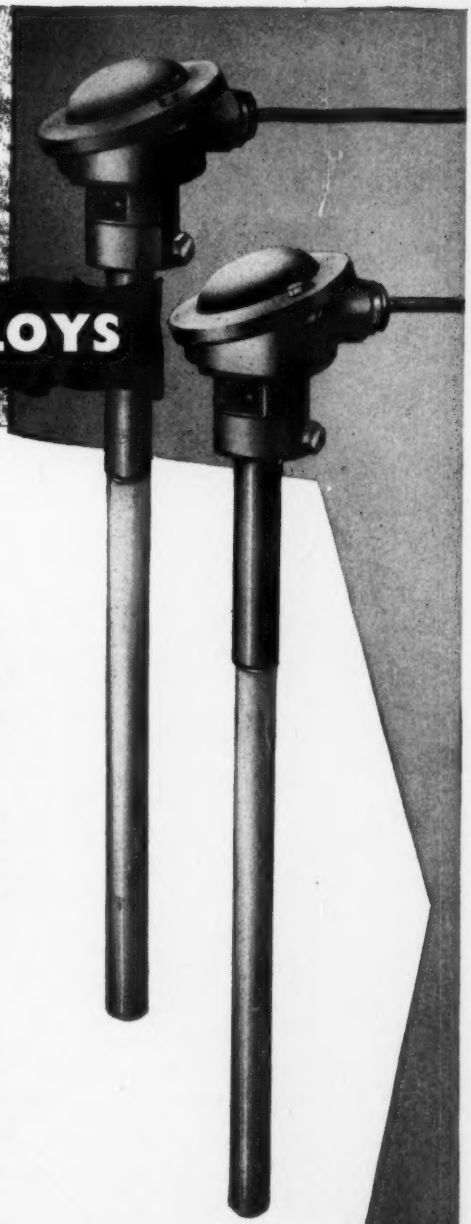

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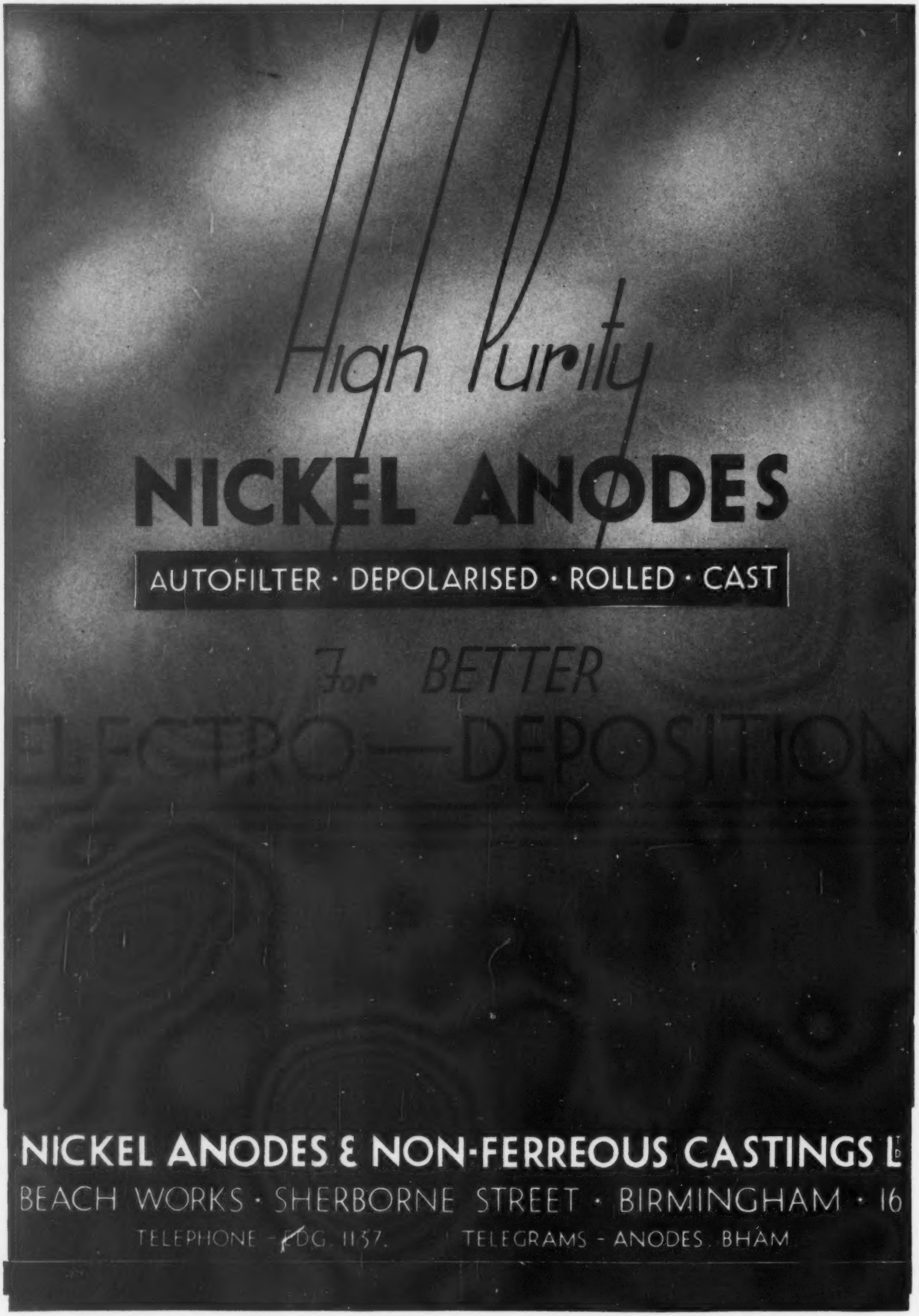
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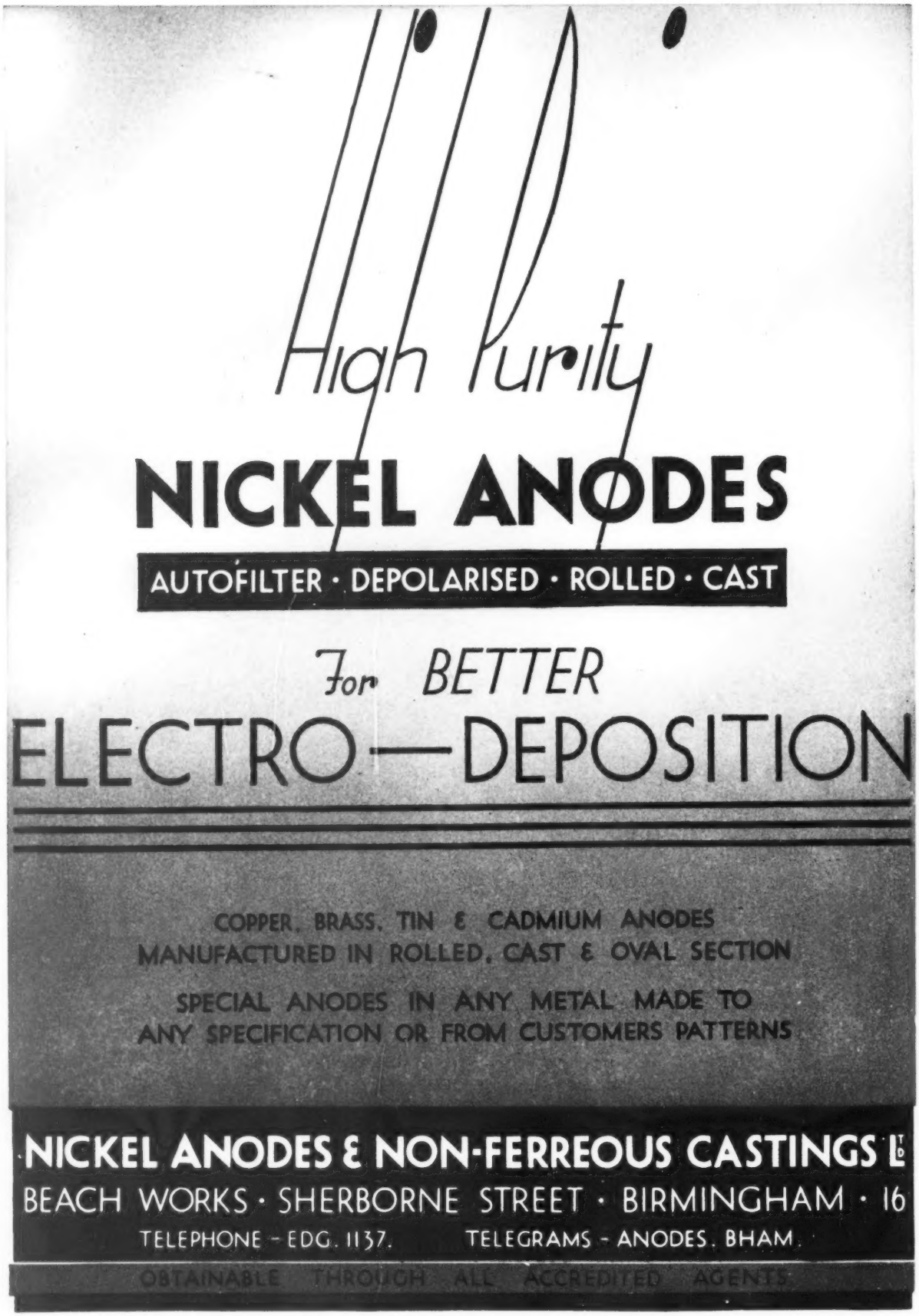
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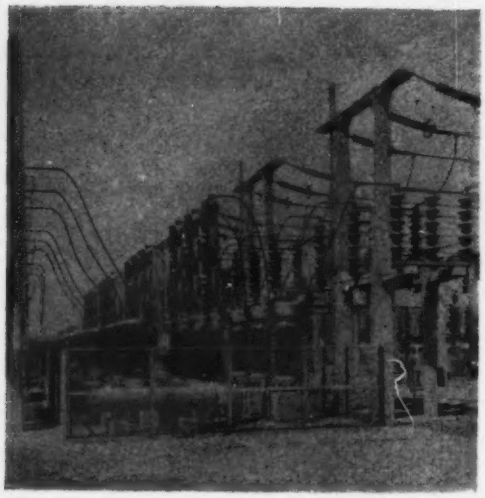

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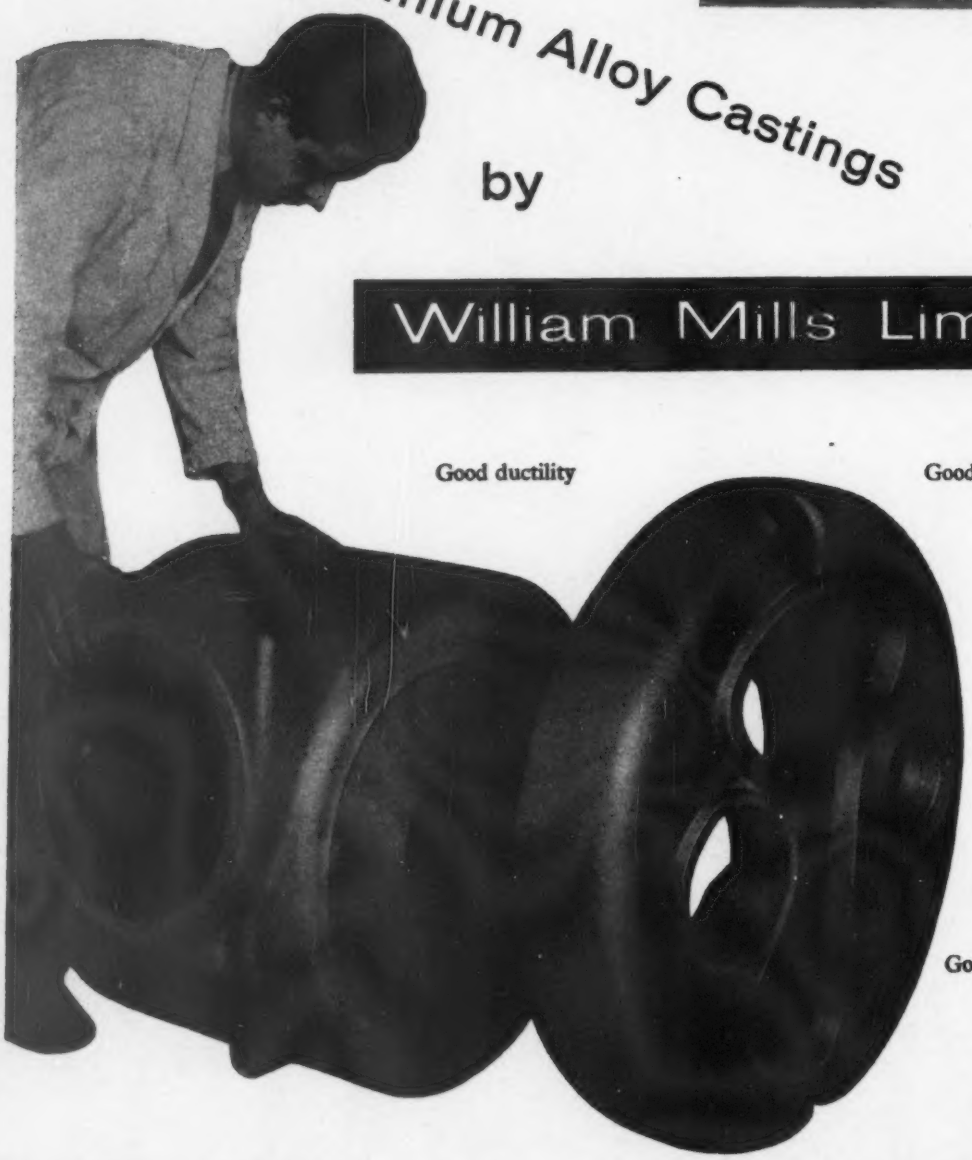

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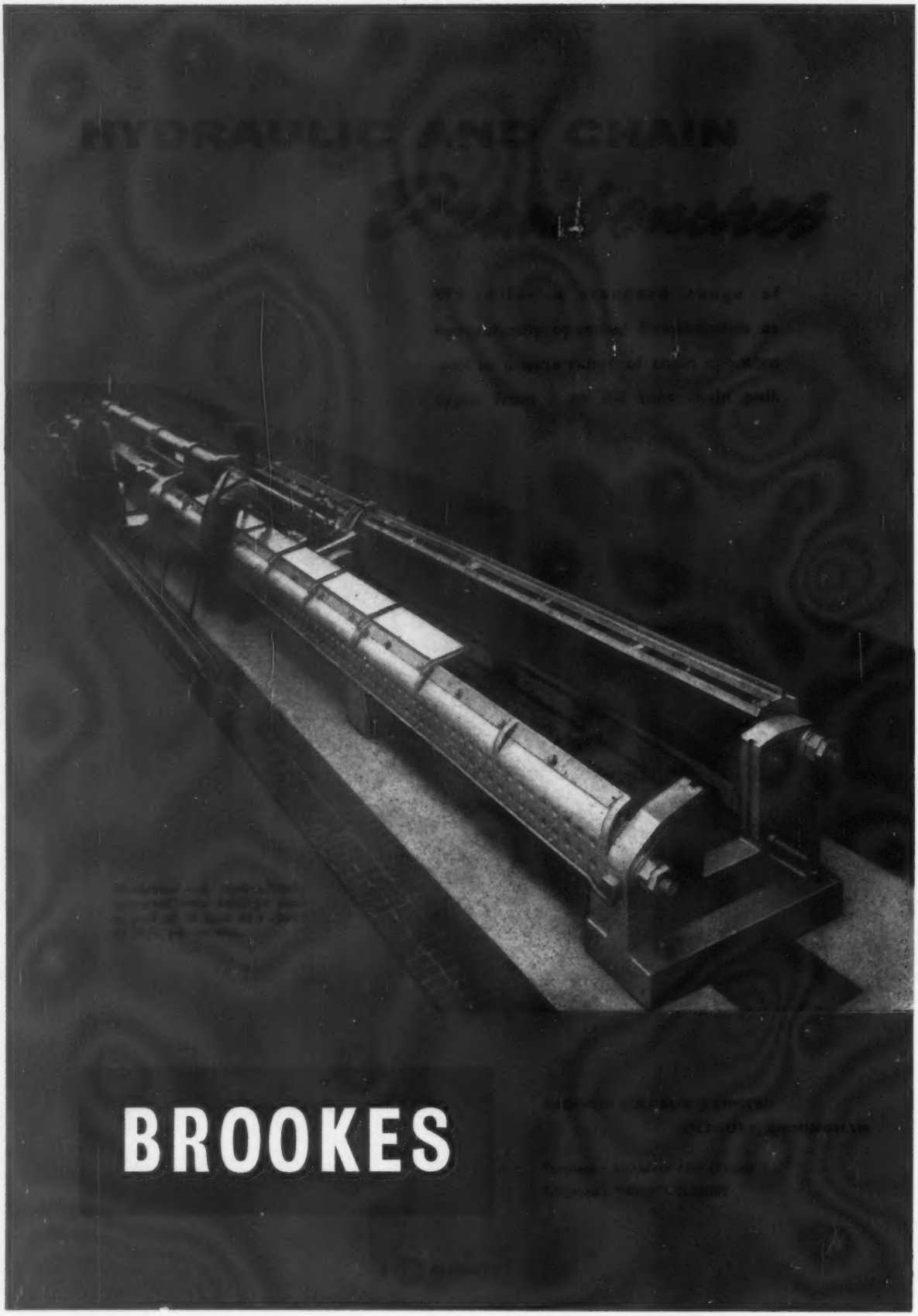
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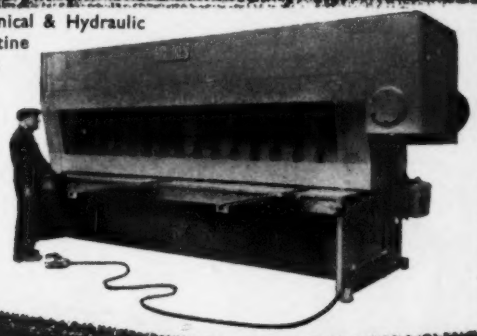

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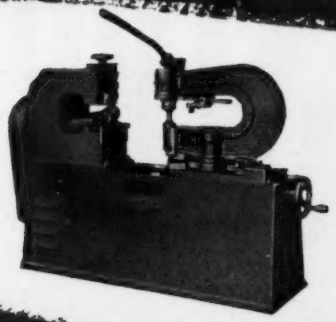

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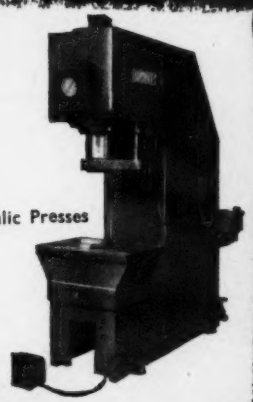

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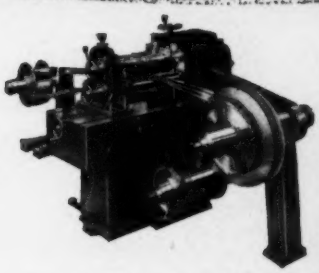

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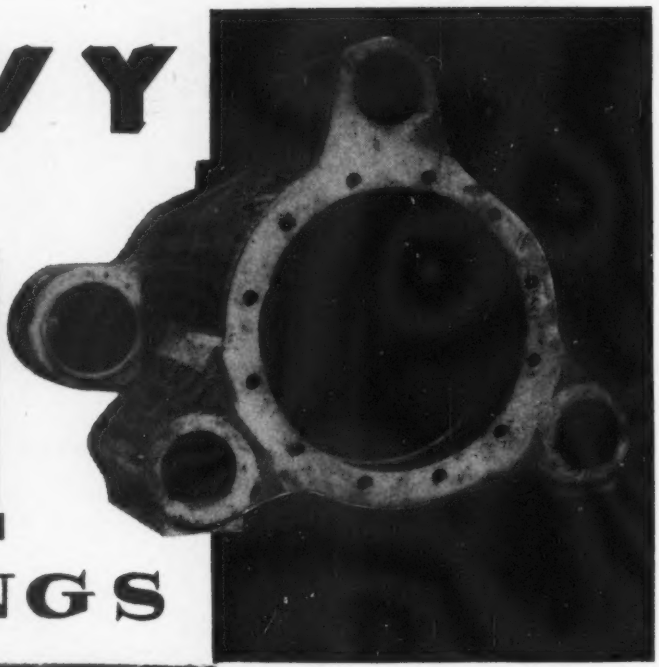

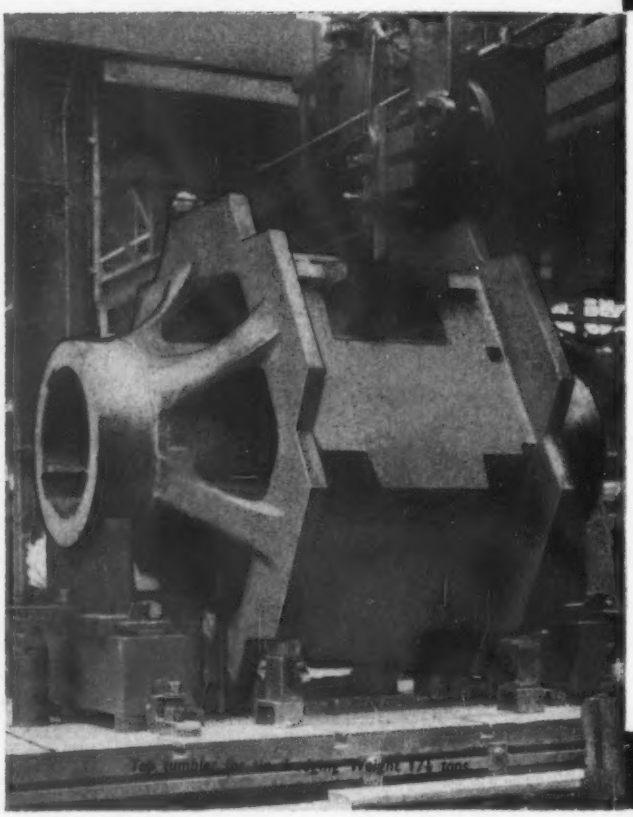

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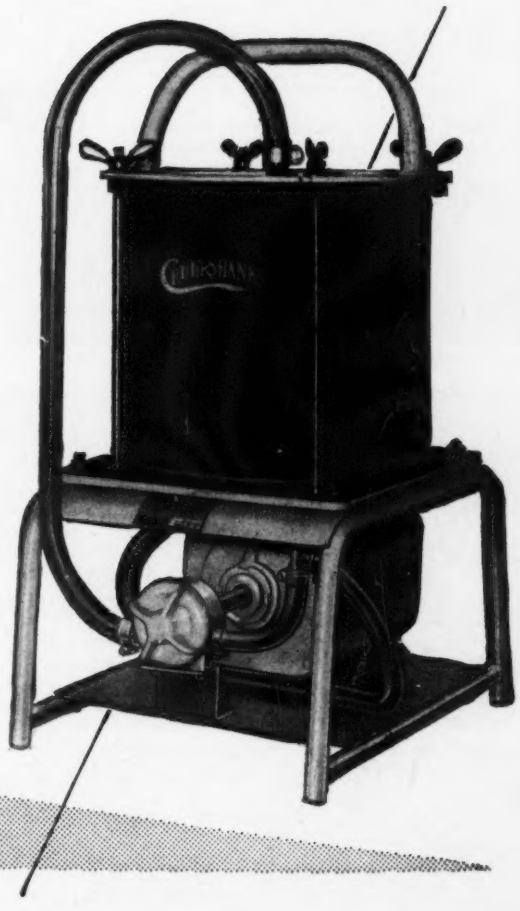

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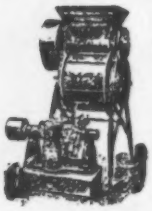

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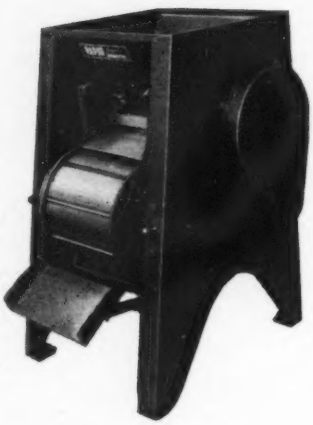

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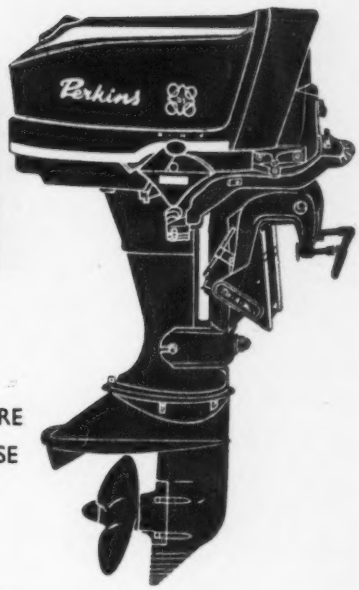

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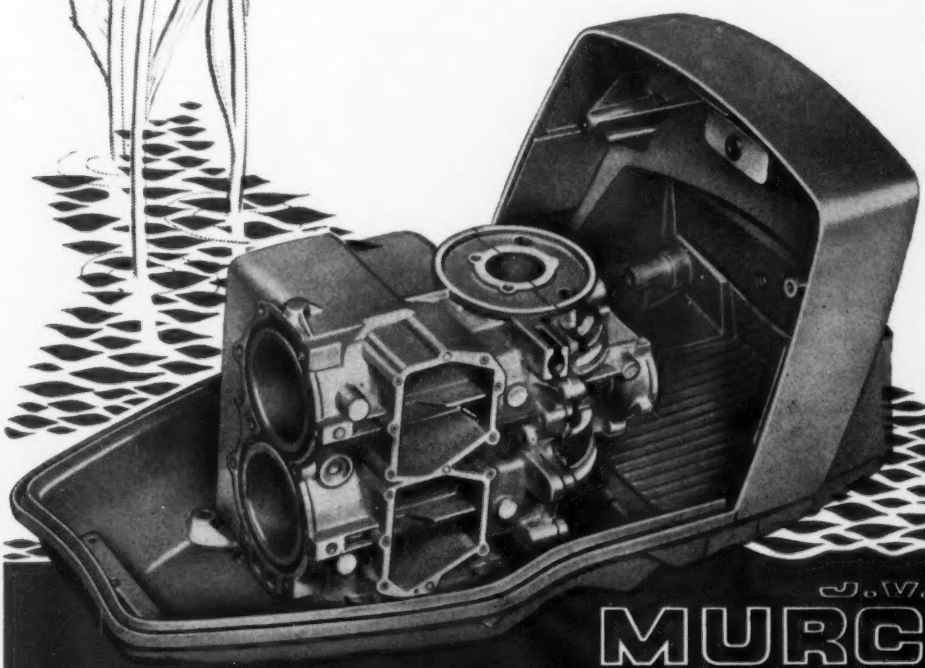

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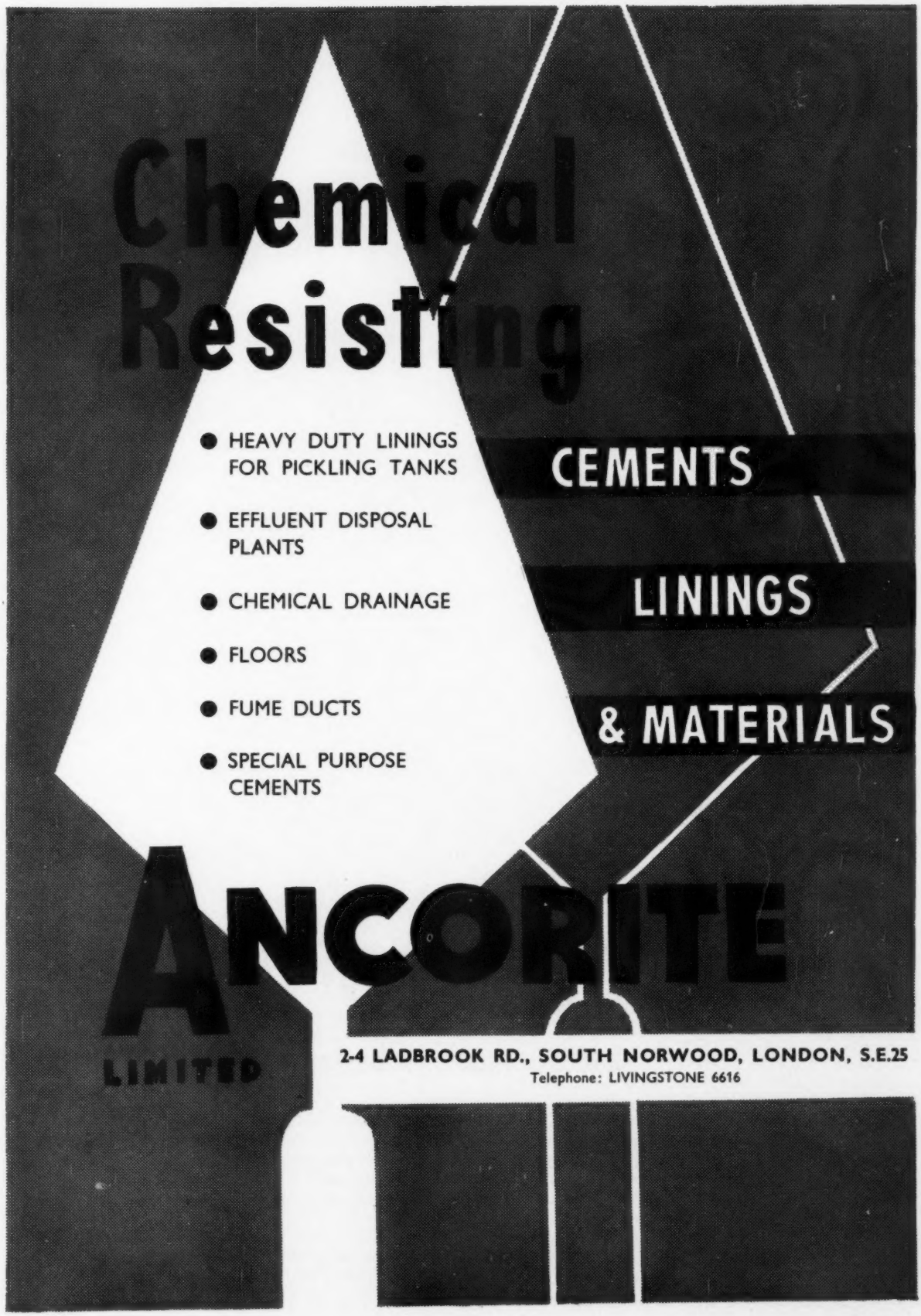
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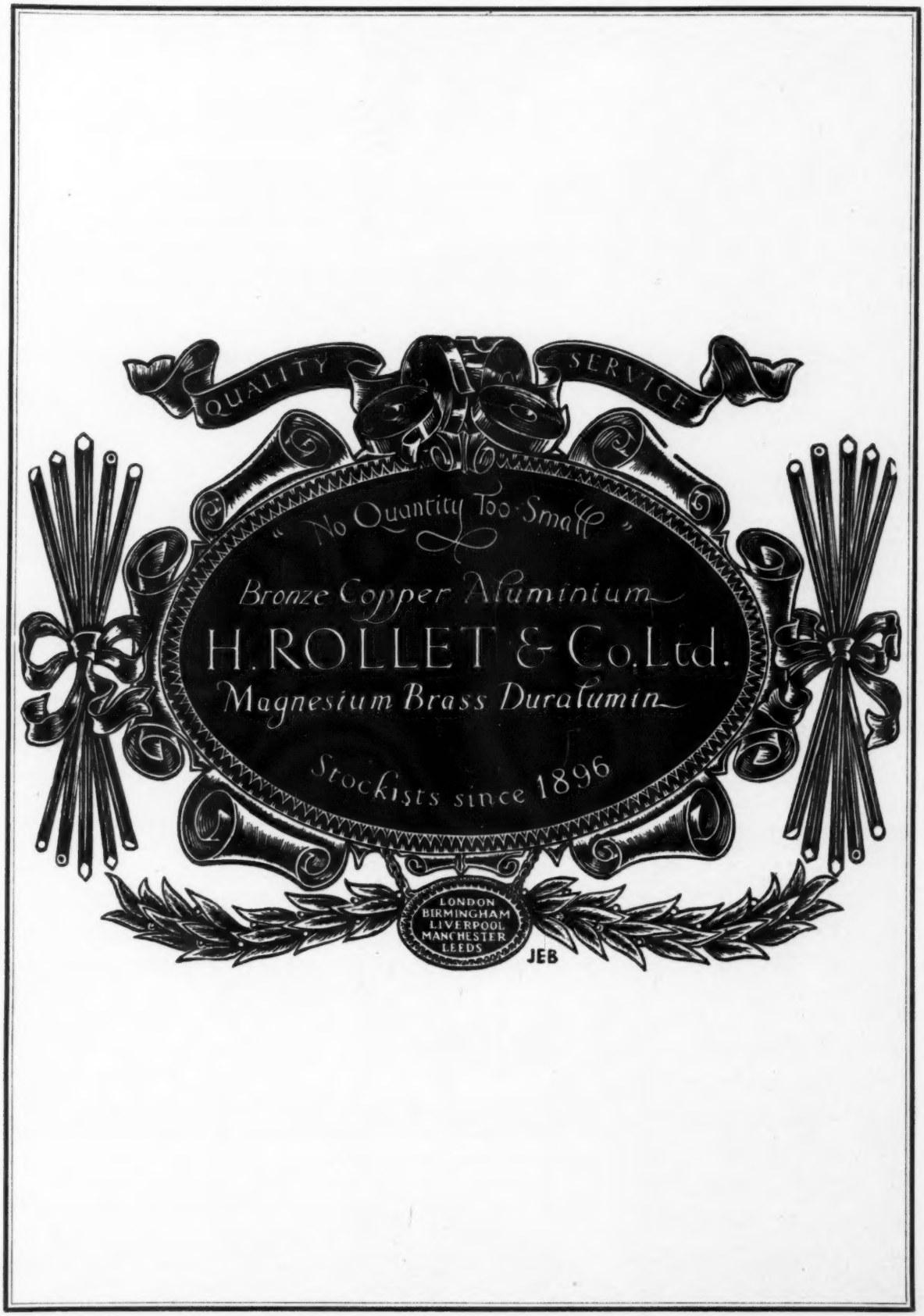
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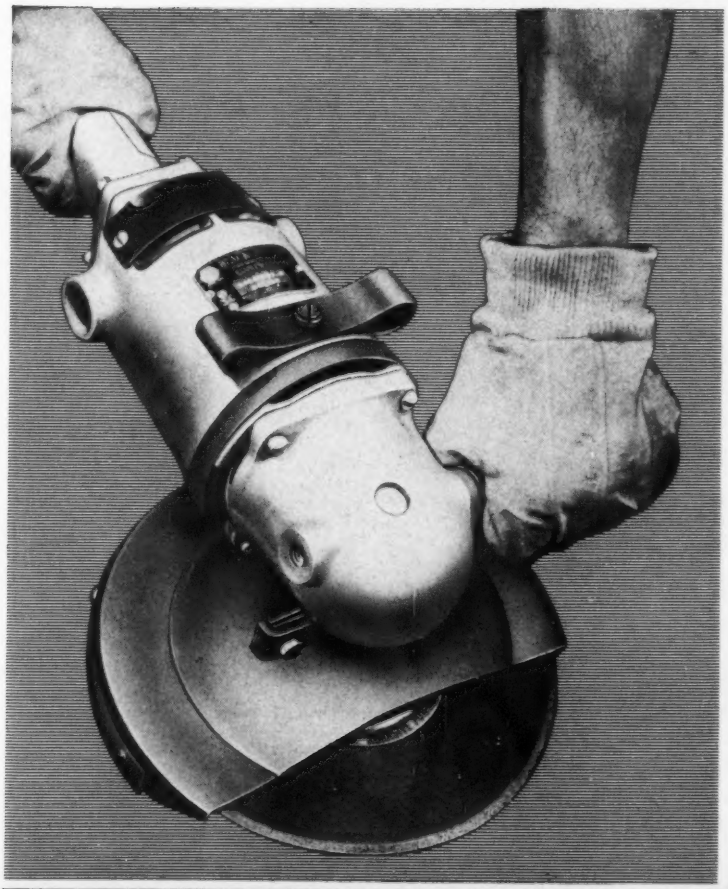

The only Angle Grinder with the GUTS to give you 12 months free servicing

After all other Grinders had failed, The Maestro Welding & Engineering Co. Ltd. (Government contractors under stringent A.I.D. inspection) put six of the new Black & Decker Angle Grinders to work. Each machine was given a tough 1,000 hour trial. Then performance was compared with that of previous machines.

Maintenance and grinding wheel costs were DOWN. Production figures and operators' piece work earnings were UP.

The new Black & Decker machine stays on the job longer—needs far less servicing—than any other Angle Grinder. That's why, as a guarantee of our confidence, we're giving a 12 months free repairs and servicing* certificate with every machine bought between now and December 31st, 1959.

Attachments available for Planing, Sanding, Cutting, Wire Brushing, etc.

**Black & Decker*

Black & Decker operate the largest electric tool service organisation in the country, with nine branches alerted for 24-hour service!

Black & Decker

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BLACK & DECKER LTD., HARMONDSWORTH, MIDDLESEX.

Please send me more information about your new Heavy Duty Angle Grinder ☐ *Please arrange a demonstration* ☐ *(Tick where necessary)*

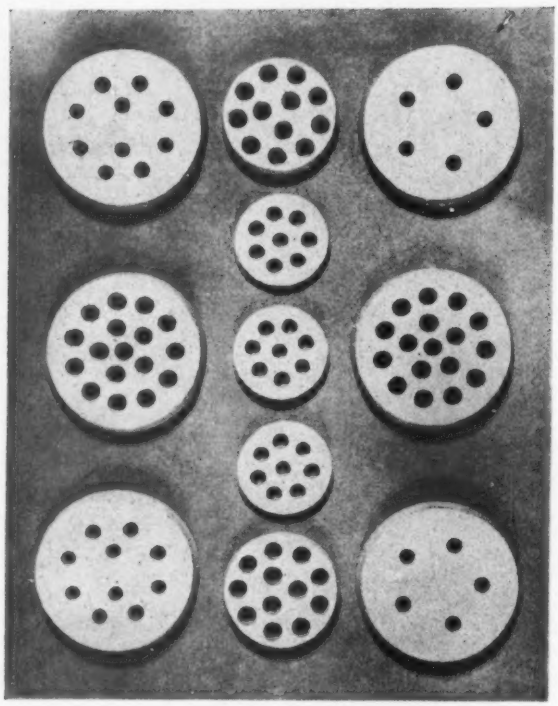
NAME .....

COMPANY .....

ADDRESS MI3

Ensure Clean Castings by using

KERAMITE STRAINER CORES



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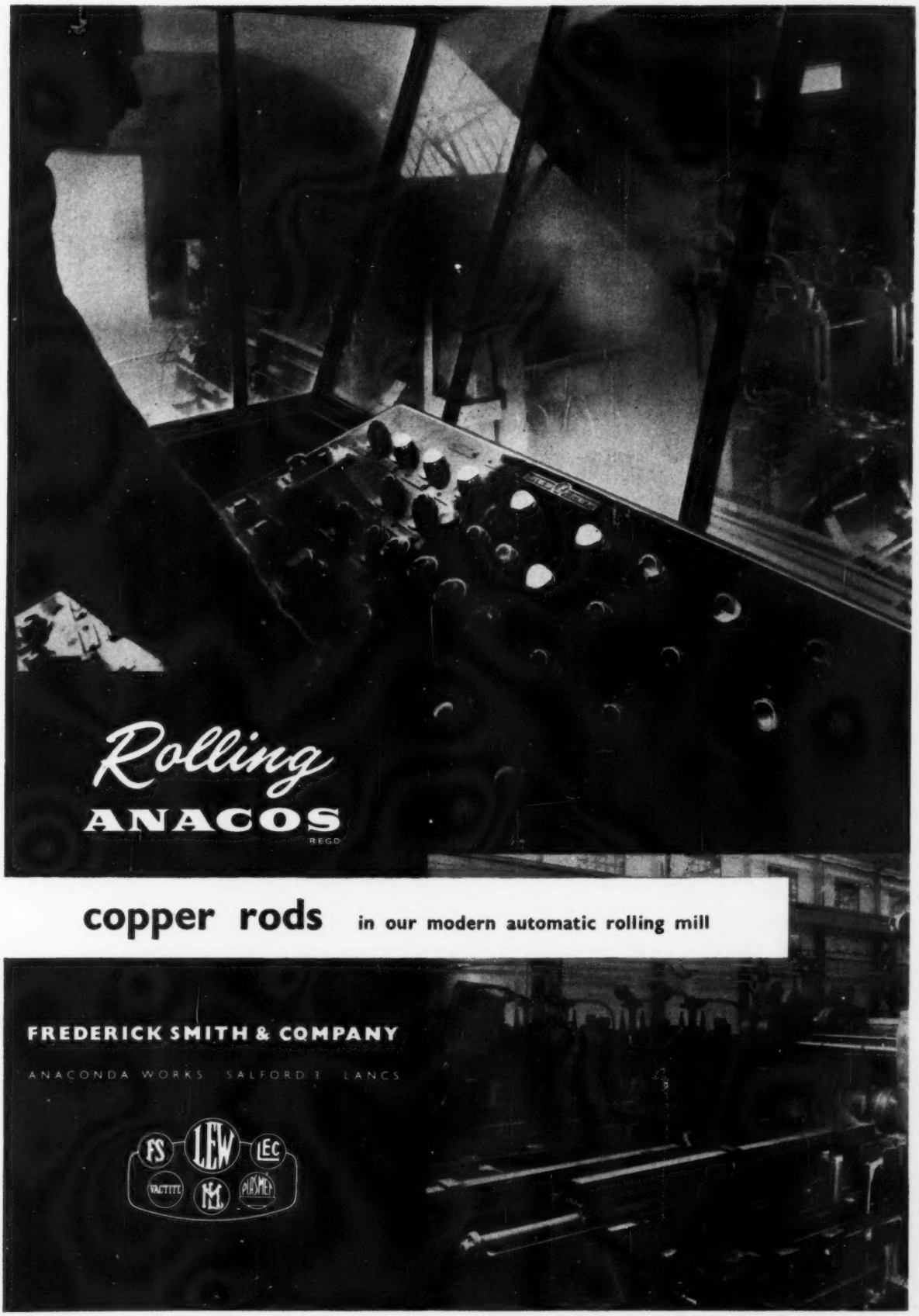
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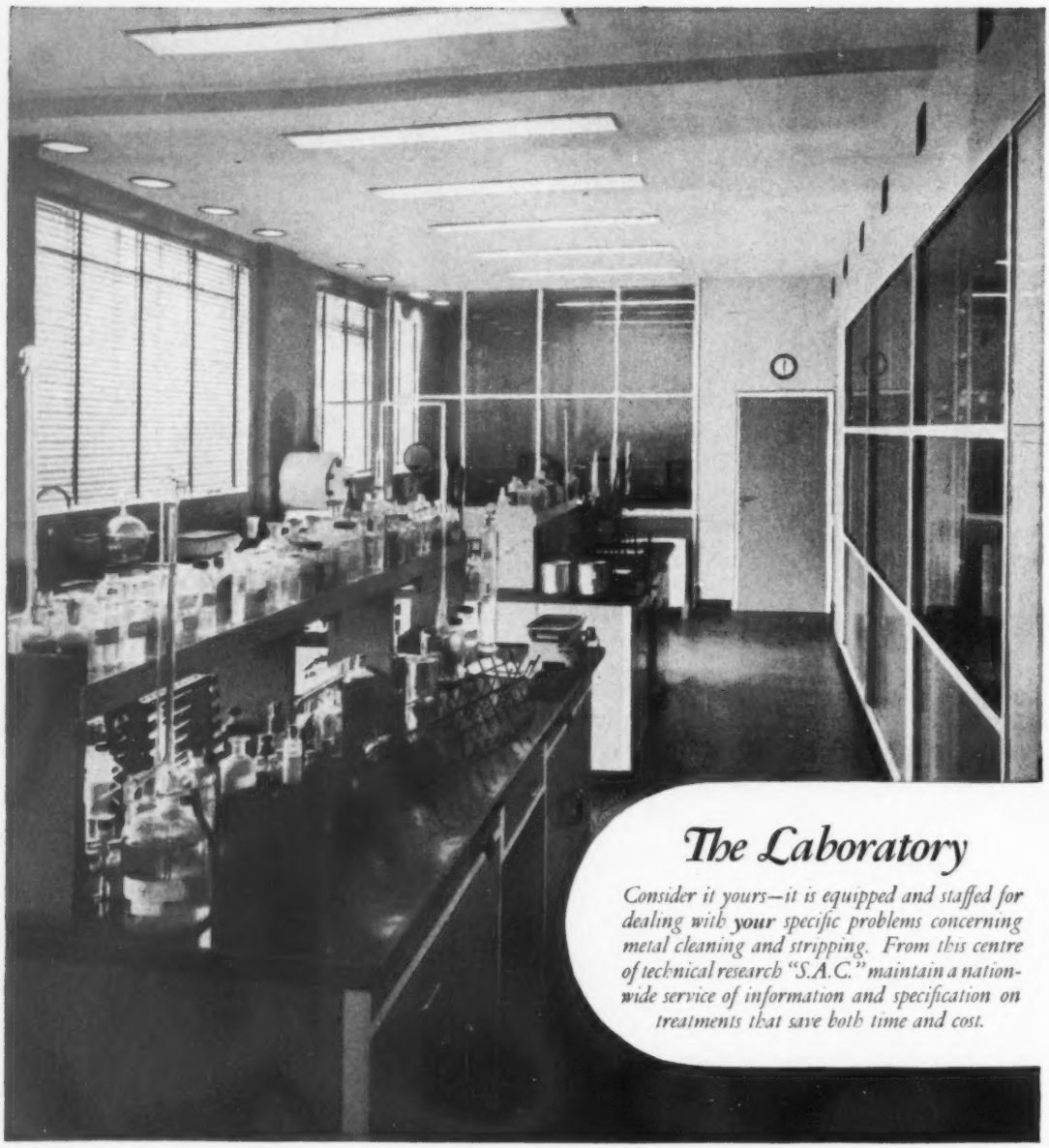

The Laboratory

Consider it yours—it is equipped and staffed for dealing with ***your*** *specific problems concerning metal cleaning and stripping. From this centre of technical research "S.A.C." maintain a nation-wide service of information and specification on treatments that save both time and cost.*

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Nitrogen and Hydrogen for Industry

I.C.I. Ammonia provides industry with a cheap and reliable source of pure nitrogen and hydrogen. And I.C.I. gas generating plants are available to convert ammonia into a wide range of nitrogen/hydrogen gas mixtures.

Anhydrous Ammonia with a guaranteed minimum purity of 99.98%, to meet more exacting requirements, is offered in bulk and in a wide range of cylinder sizes.

Liquefied Ammonia (*Industrial Quality*), a cheaper grade, is available in bulk and in two-ton containers for the larger consumer, and makes possible substantial economies in gas costs.

A bulk delivery of 10 tons of ammonia provides over $1\frac{3}{4}$ million cu. ft. of nitrogen

Full information on request.

Imperial Chemical Industries Ltd., London, S.W.1.

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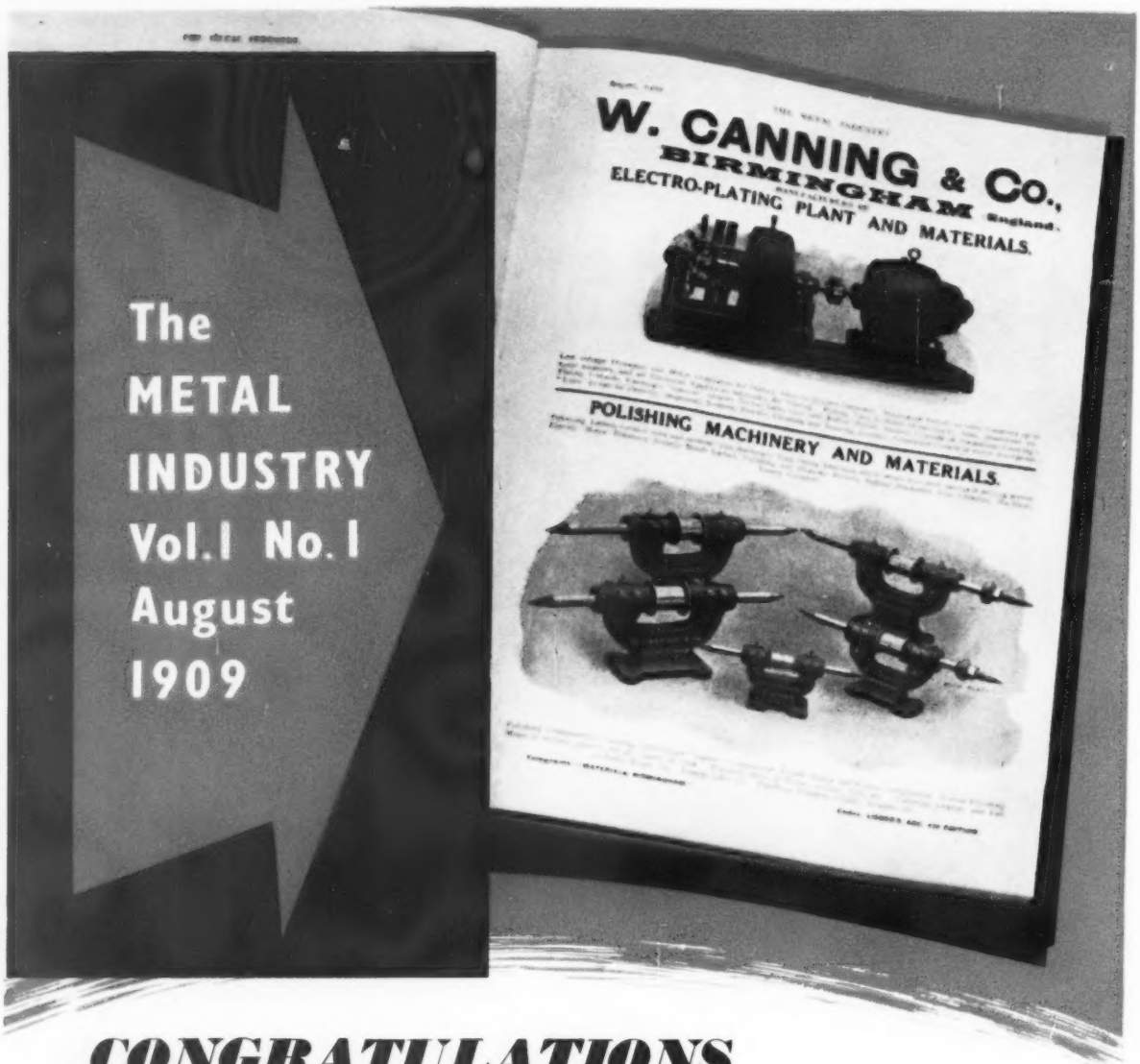

CONGRATULATIONS

to "METAL INDUSTRY"

on completing its first half century

The above advertisement appeared in the first issue of this journal. Since then, W. Canning & Co. Ltd. have continuously developed materials and equipment to meet the growing needs of expanding industry.

W. CANNING & Co. Ltd.

BIRMINGHAM 18. *Telephone: CEN. 8621*

Automatic **PLATING**

Cannings also supply anodes and chemicals for all plating processes

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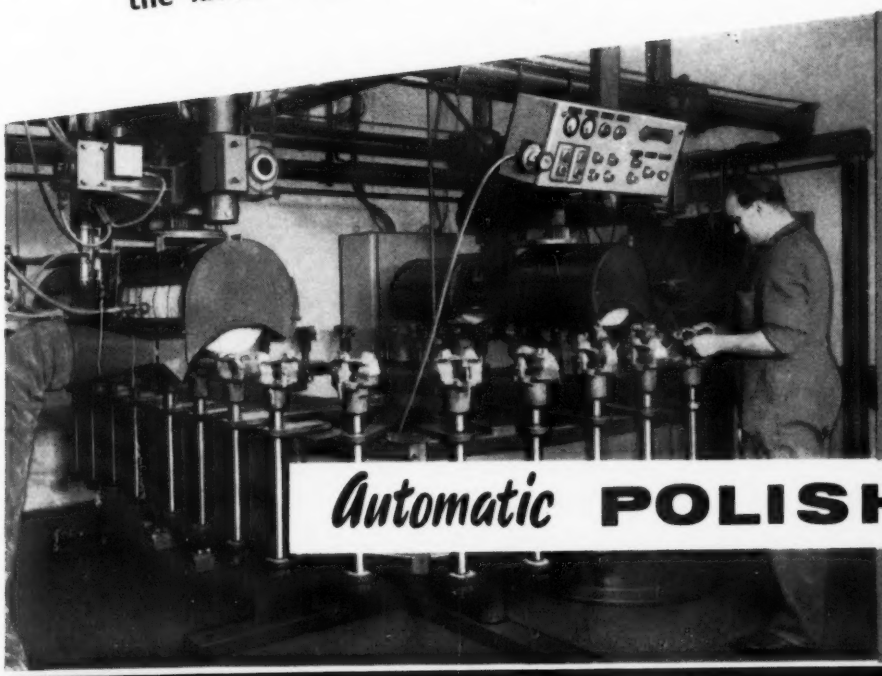
A "Vulcan" automatic plating plant

Industry is fast moving towards fully automatic processing. Canning automatic plant, for both plating and polishing, embodying the latest techniques and designs, IS AT YOUR SERVICE.



We also supply mops, compositions and all polishing requisites

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A "Uniflex" automatic polishing machine

Automatic **POLISHING**

...also at LONDON *and* SHEFFIELD...

Save on machining costs with

Holtos Bronze Shellcastings

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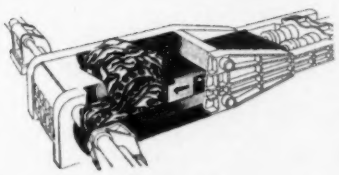
Automatic Sheet Scrap Baler

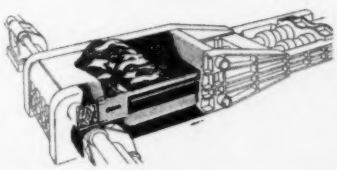
Due to the built-in horizontally working shear (on the half-pressure platen of the press) no press box lid is required, so that feeding can be done continuously.

The shear cuts off the flow of scrap material fed into the press and all further operations including bale ejection are fully automatic. Transport of finished bales by conveyor-belt.

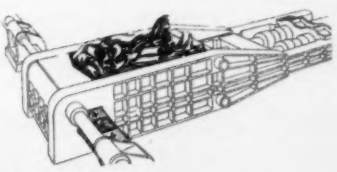
Low baling costs **High efficiency**



Advancing half-pressure ram compresses the scrap.



Protruding scrap pieces are sheared off and are left for remaining loose scrap.



Bale is finished and ejected.

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466, Royal Exchange, Manchester 2. Tel: Deansgate 5131

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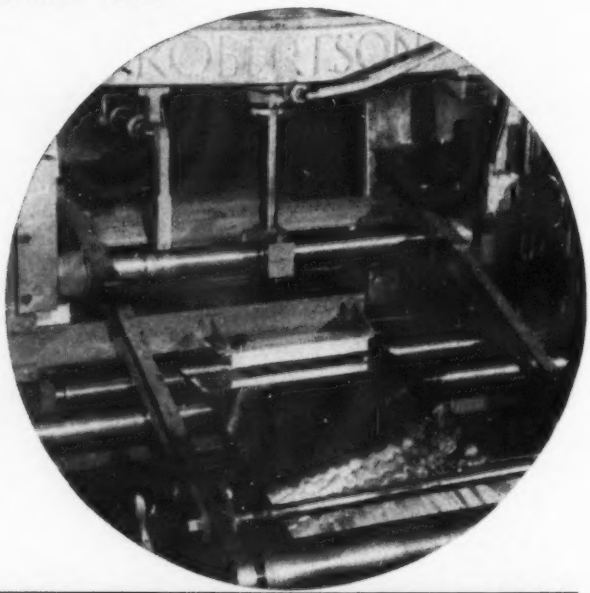
Baldwin Atomat Nucleonic Thickness Gauges

ACCURATE, CONTINUOUS, NON-CONTACT INSPECTION

SAVES MATERIAL, LABOUR AND TIME!



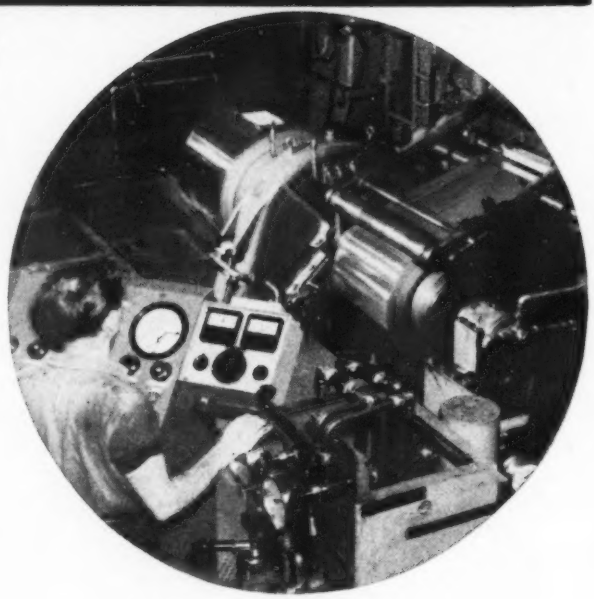
The Atomat Principle

RAY SOURCE
MATERIAL
RAY DETECTOR
Amount of rays passing through material indicates thickness or weight per unit area.

That's the very basic explanation of the Atomat principle. There are three main gauges; the Atomat Cold Strip Gauge, the Hot Strip Gauge and the Beta Gauge.
In addition there are special purpose variations, made to meet the requirements of many different industries.

HERE'S WHAT AN ATOMAT GAUGE CAN OFFER YOU

- **Time and material saving both in production and setting up**
- **High accuracy**
- **Calibration in your usual units of measurement**
- **Continuous readings for materials in constant production**
- **Auto standardisation and control if you require**
- **Minimum maintenance**



Baldwin Atomats are already boosting production and cutting costs in the paper, metal rolling, rubber and plastics industries. Highly successful applications also include the measuring of selenium on aluminium, coatings of paint and lacquers, density of wood chips, coatings of grit on abrasive papers and padding and resin impregnation in the textile industry. But the potential of Baldwin Atomat Nucleonic Gauges has hardly been tapped.
Is there a place for them in your plant?

INSTRUMENT DIVISION

Send for the Baldwin Brochure M.I.124
It gives full information on Atomat Gauges clearly and concisely.

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WITH PROGRAMME SELECTOR
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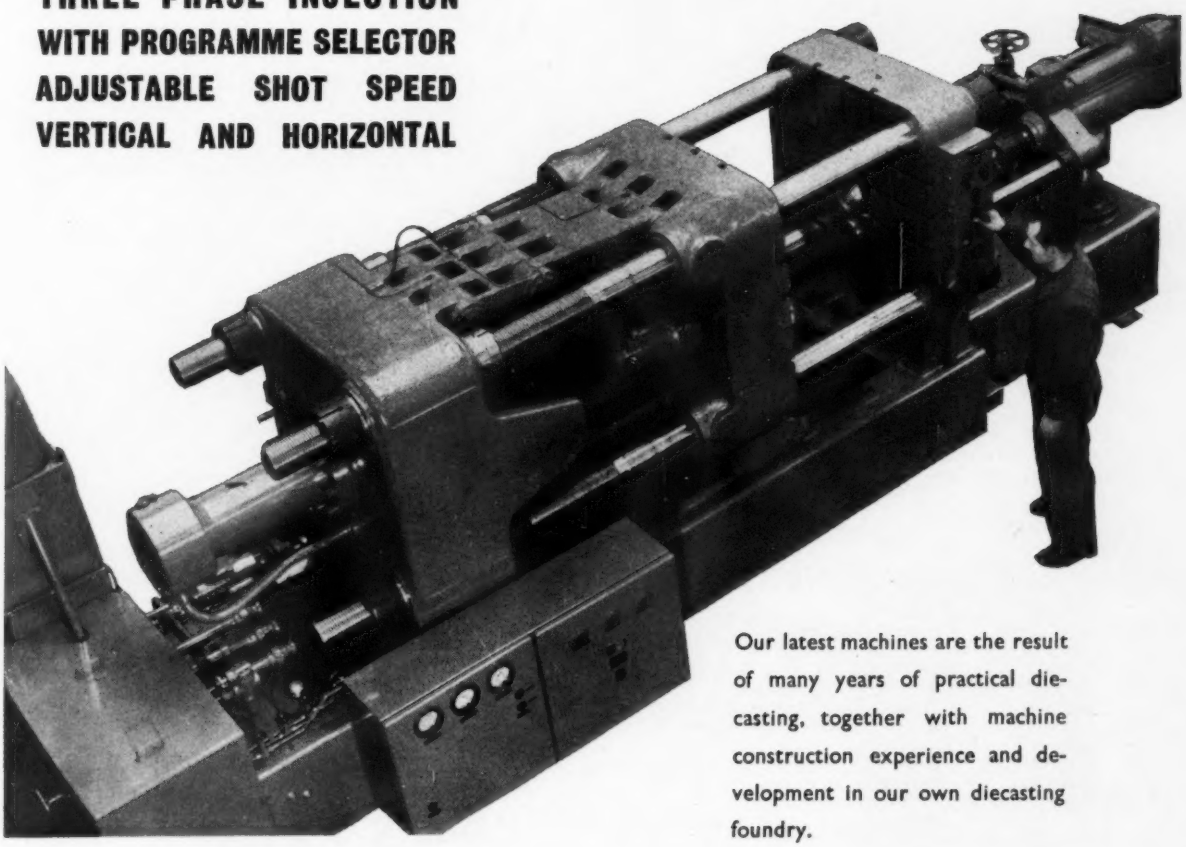

Our latest machines are the result of many years of practical die-casting, together with machine construction experience and development in our own diecasting foundry.

Die design and die making departments are at the disposal of our customers at all times.

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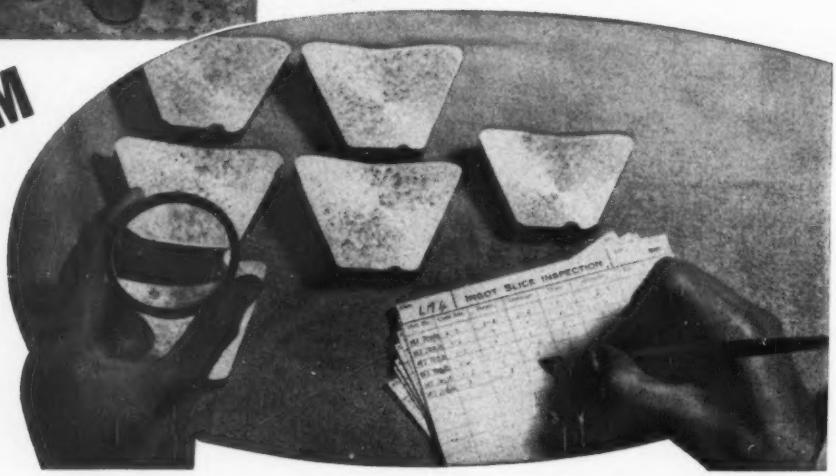

Intensive Research and Quality Control ensure that you can depend on the uniformity of

Unceasing research and strict quality control, at all stages of production, ensures that Intal Light Alloy Ingots can always be depended upon. The quality never varies. With over a quarter of a century's experience and progress, Intal maintain all the newest techniques in scientific inspection, and make use of the most advanced instrumentation in ensuring that the Intal high standard of quality is consistently maintained.

INTAL

Light Alloy Ingots

These illustrations are taken from the latest Intal booklet, giving much interesting information on alloy ingot manufacture. We shall be pleased to post a copy to executives on request.

INTERNATIONAL ALLOYS LTD

HAYDON HILL, AYLESBURY, BUCKS. Telephone: Aylesbury 4242. Telex. 15/520 Cables: Intalloyd, Aylesbury

Brass

In Billet, Ingot or Strip form, to British Standards Specification.

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Sheet and Pipe to British Standards Specification.

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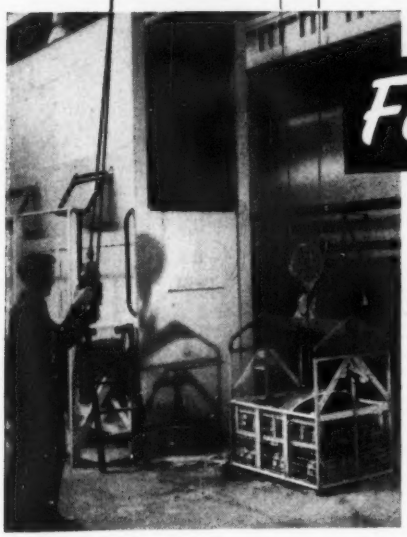
To British Standards Specification.



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The Mould Metal Fabrication Service trims the time and cost on all your jobs—light or heavy, small or large. Working either to your specifications or producing our own designs, we can offer unequalled service for fabrications and pallets.

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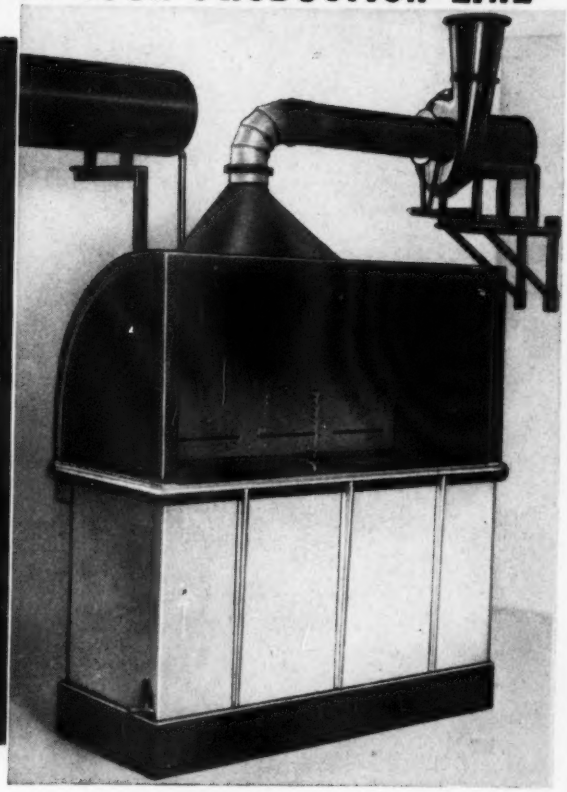
How you can

Pickle and Bright Dip *IN YOUR PRODUCTION LINE*



New Extraction Cabinet ends acid fumes and gas menace

***Exclusive* ammonia vaporizing system ensures *complete* neutralization**

High impact p.v.c. ensures greater strength to the unit

Complete with extractor fan and ducting: simple to install

Transportable and adaptable

'In line' dipping and pickling—improves production flow, saves time

Safeguards operators : protects plant and premises

With this new low-priced extraction unit, developed and manufactured by the Hockley Chemical Co. Ltd., complete neutralization is ensured by a new and exclusive ammonia vaporizing system. This system results in high efficiency at low operating costs. Its competitive price, easy installation and maintenance (together with the more obvious and essential advantages), makes the unit ideal for the smaller manufacturer.

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for ALUMINIUM, MAGNESIUM, ZINC ALLOY and FERROUS METALS

a New
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EFCO DI-PHASE CLEANERS

These consist of two distinct liquid phases which contact the work simultaneously. They are non-corrosive, protect ferrous work from subsequent rusting and effectively remove a wide range of soils.

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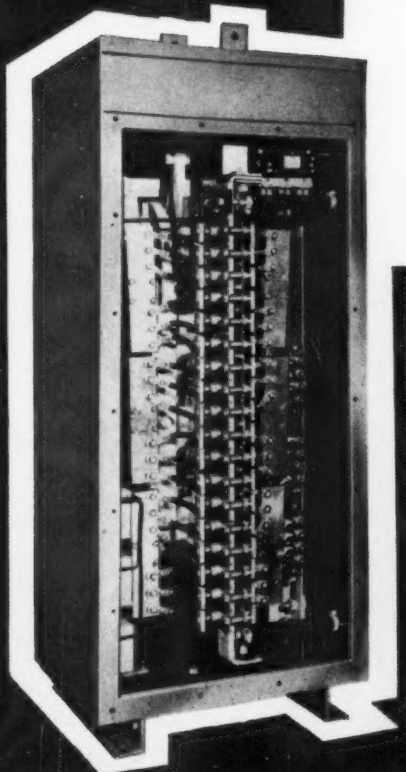

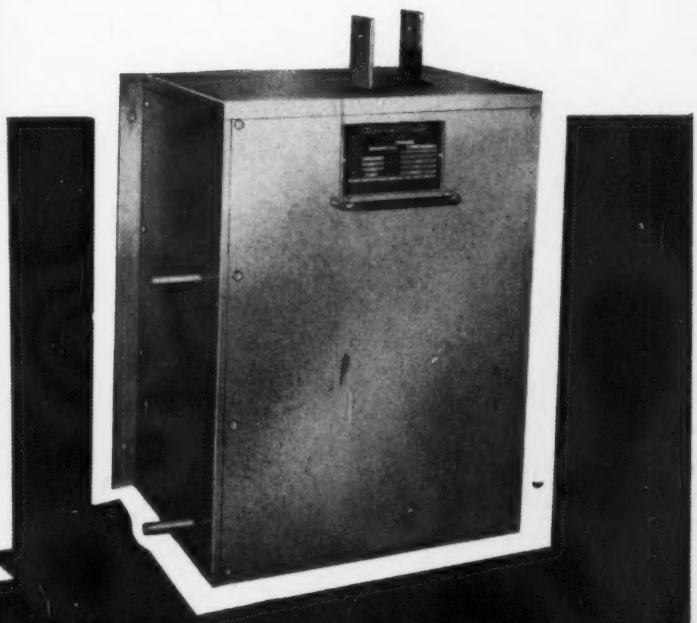

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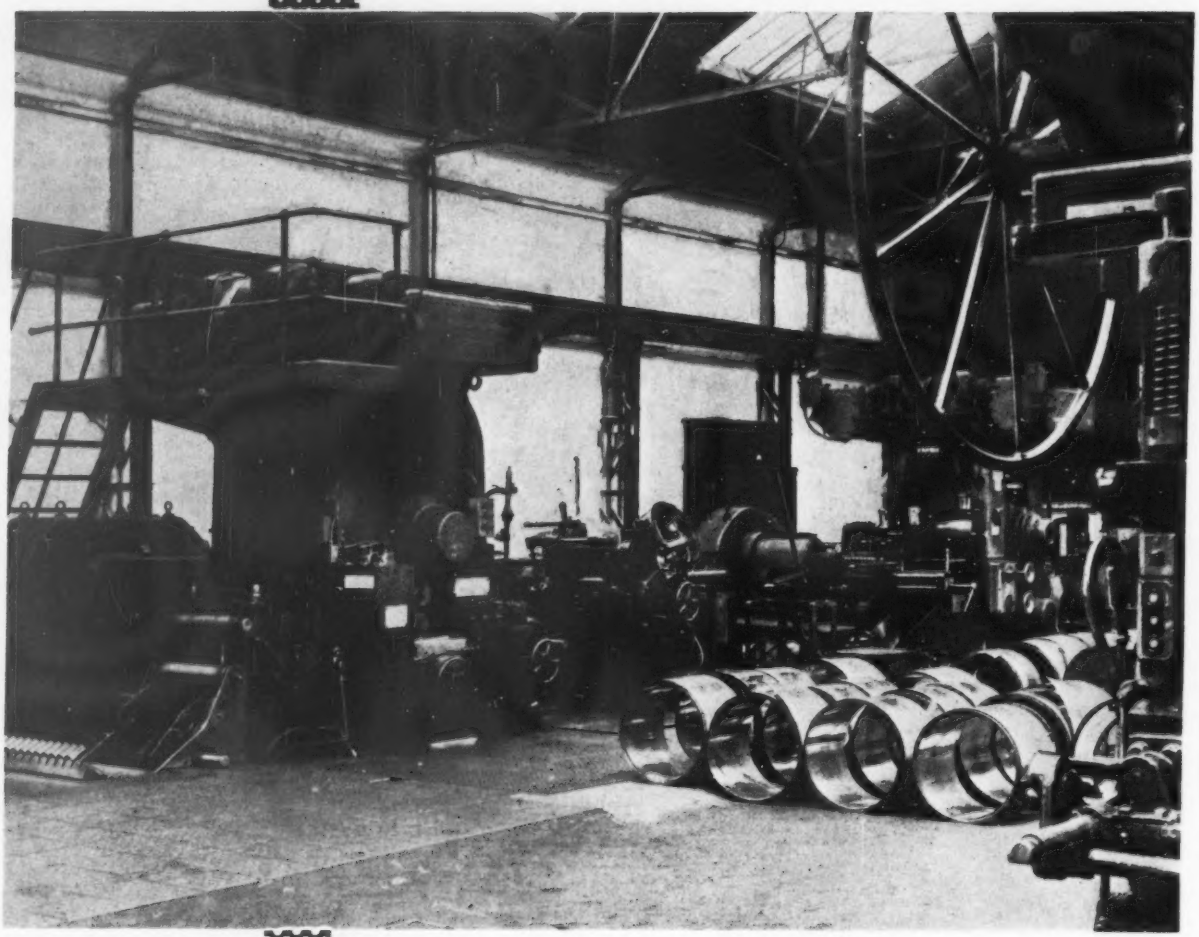

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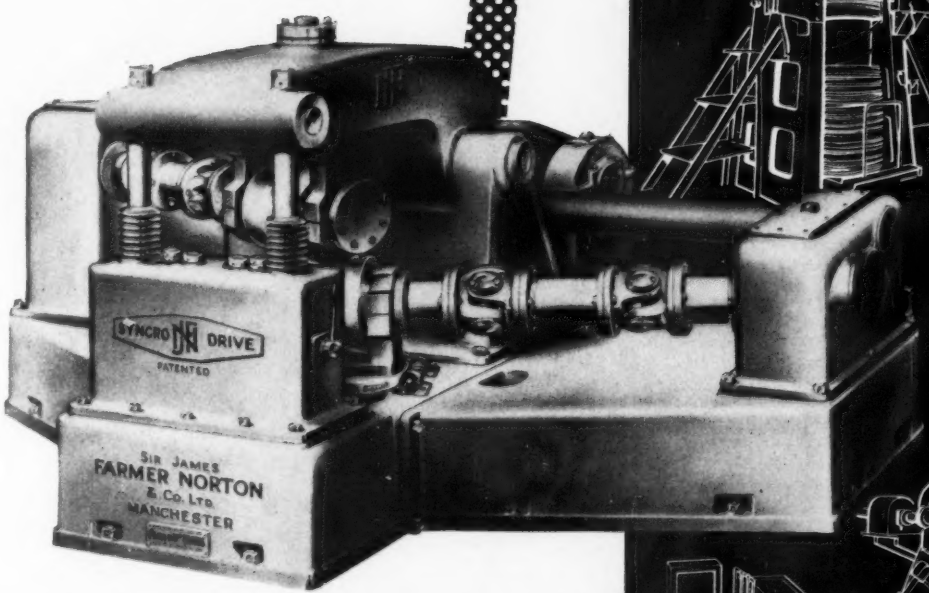
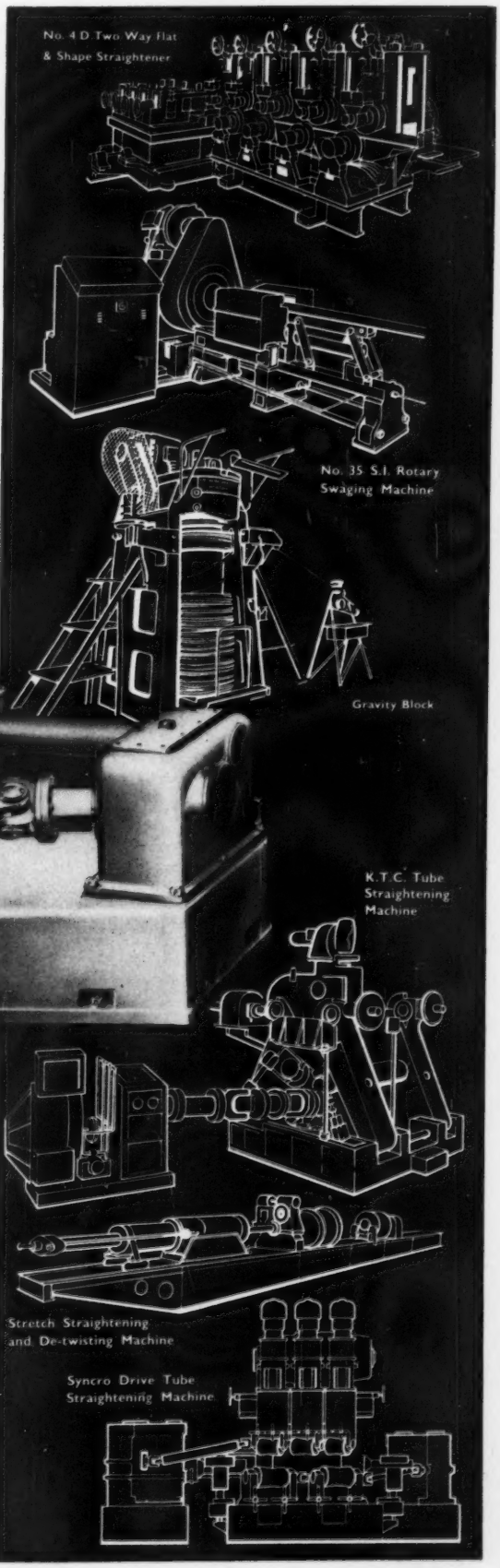


3V-SD 2 ROLL ADJUSTABLE ANGLE BAR AND TUBE STRAIGHTENING MACHINE

Capacity 12 m/m to 75 m/m diameter mild steel.
Throughput speed 15 to 45 metres per minute.
Differential drive giving absolute synchronization of roll speed.
Hydraulic adjustment of roll pressure.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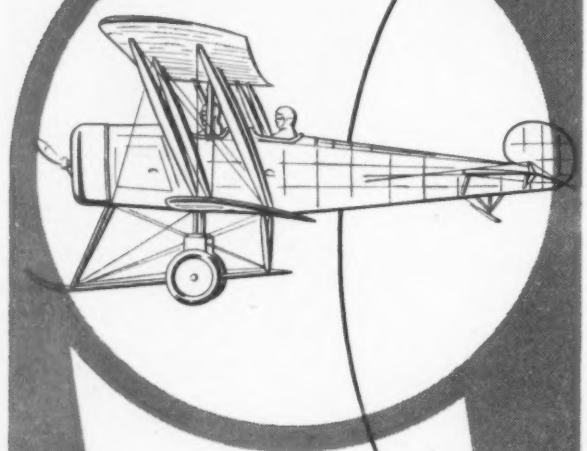
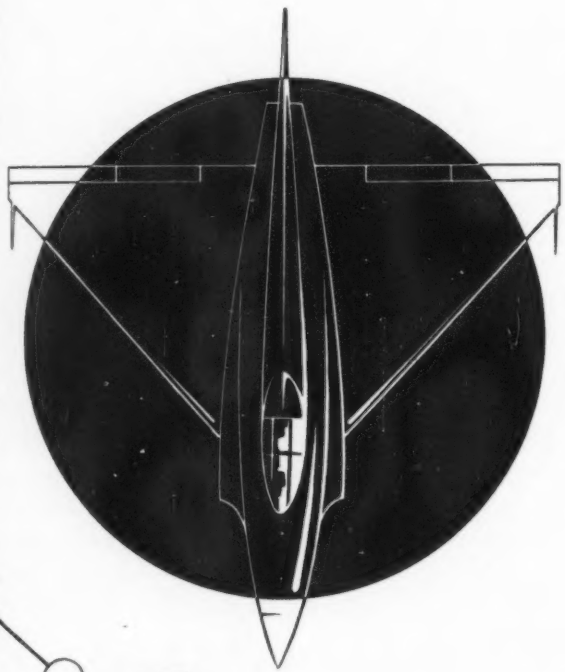
Pattern of Progress

The incredible speed of development, particularly in the last half-century, proved a formidable challenge to the efficiency and adaptability of industry. The very fact that this live Company still leads in design and manufacturing techniques is a glowing tribute to the co-ordinated efforts of management and workers.





E. CAMELINAT & CO. LTD.
for the design and production of complete units demanding specialist experience.

Camelinat

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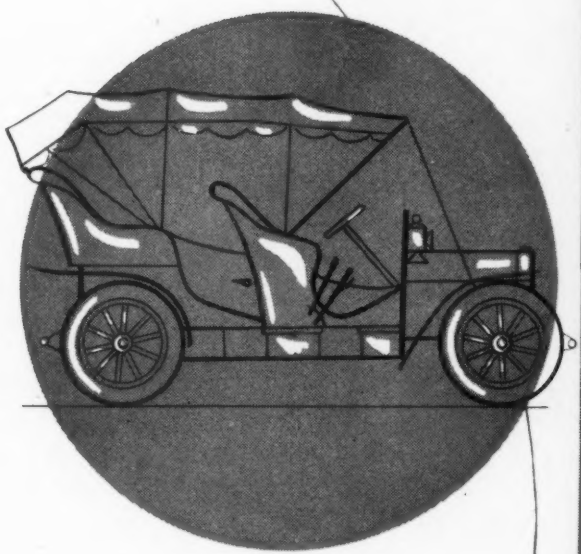
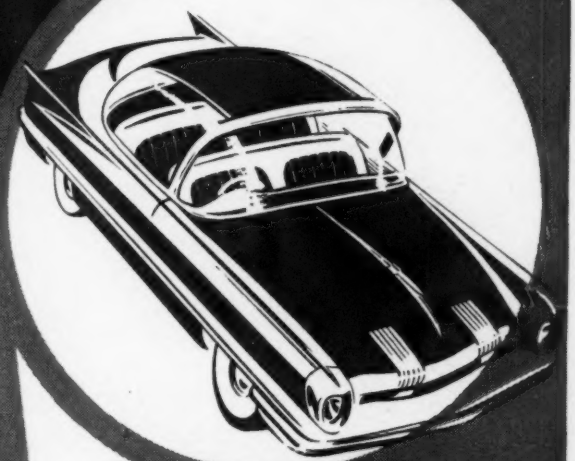
Phone: CENtral 6755 (5 lines) Grams: CAMELINAT, BIRMINGHAM.

SM/EC 2956

Pattern of Progress





Today's Mass Production means another car for the road every minute of the day.

Camelinat have good reason to be proud of their own achievement in keeping pace with the ever increasing demands of the motor industry.

Camelinat

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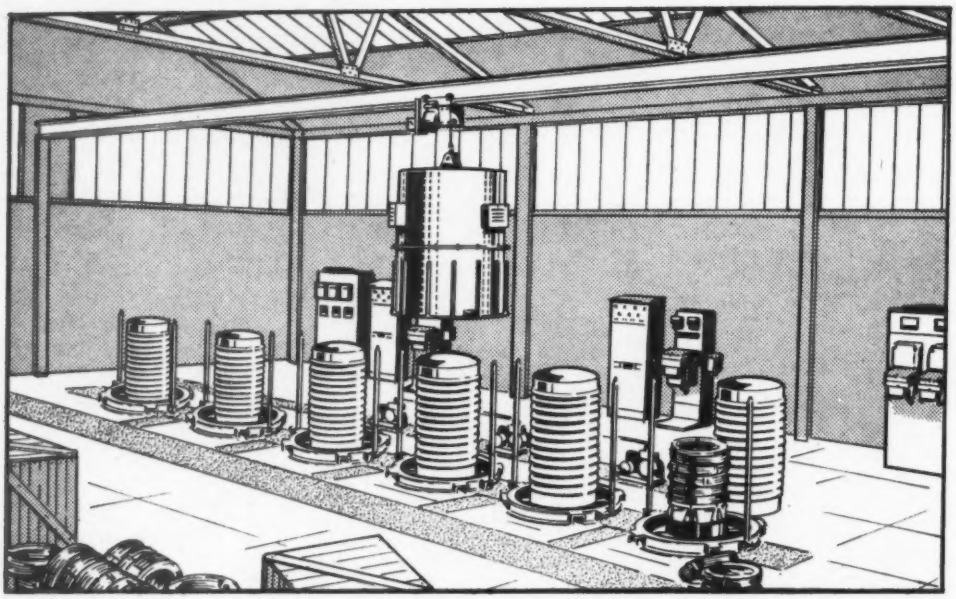
Phone: CENtral 6755 (5 lines) Grams: CAMELINAT, BIRMINGHAM.

E. CAMELINAT & CO. LTD.
for the design and production of complete units demanding specialist experience.

SM/EC 2815

Vacuum Heat Treatment Furnaces



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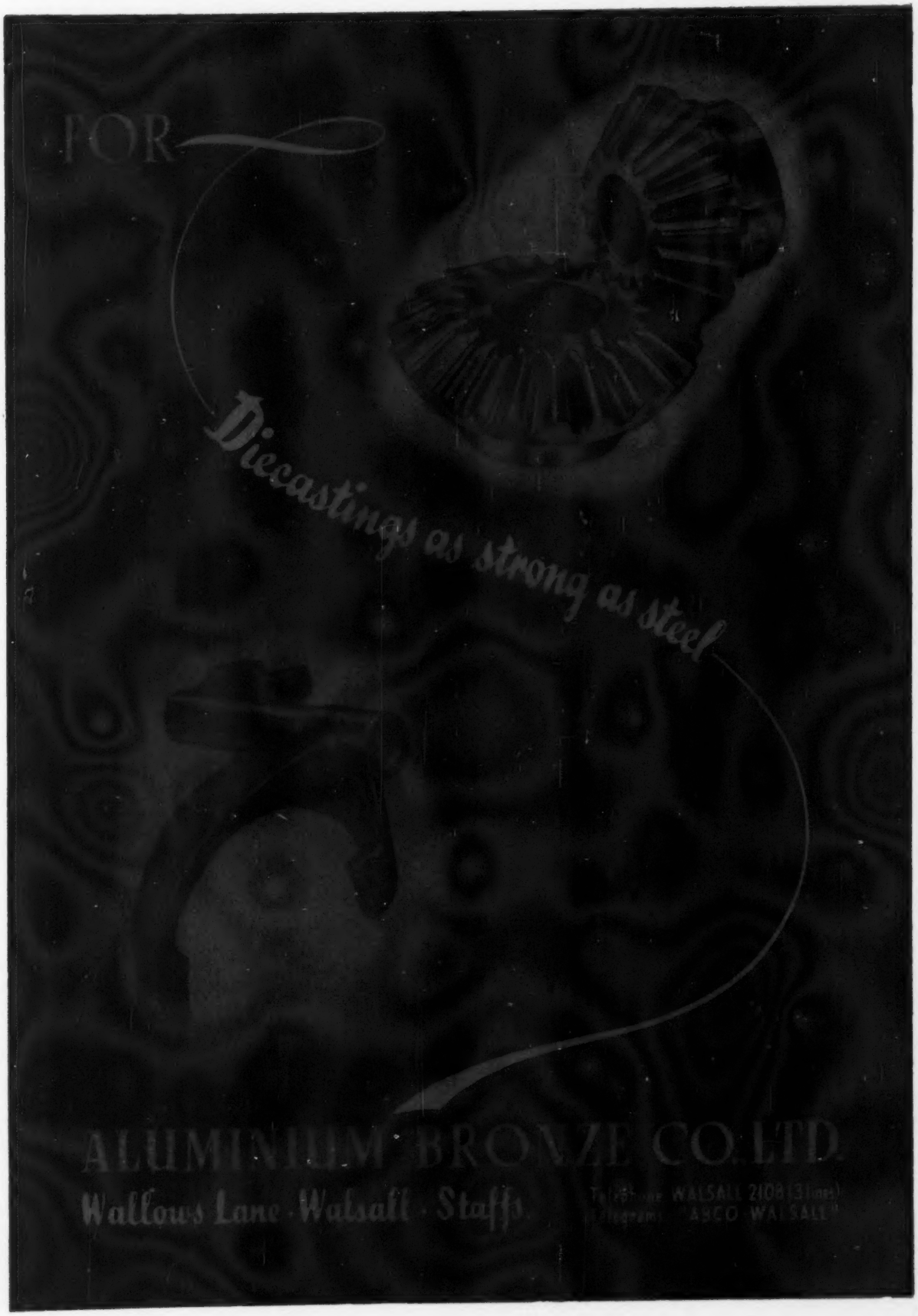
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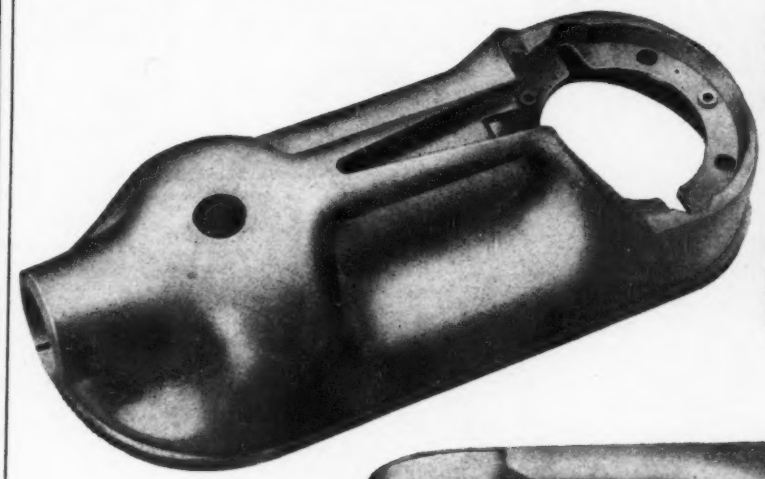

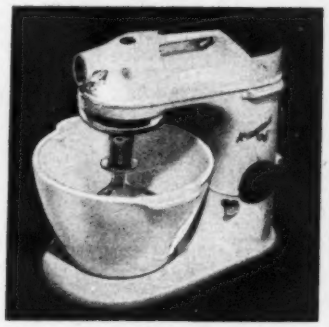

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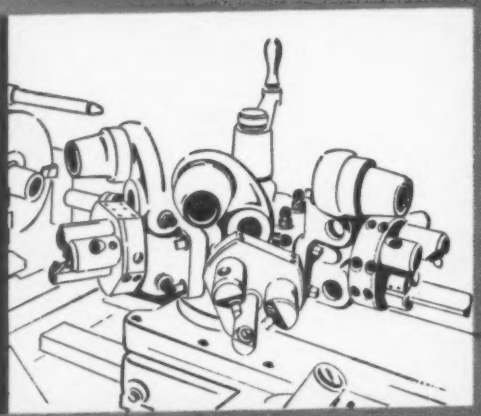

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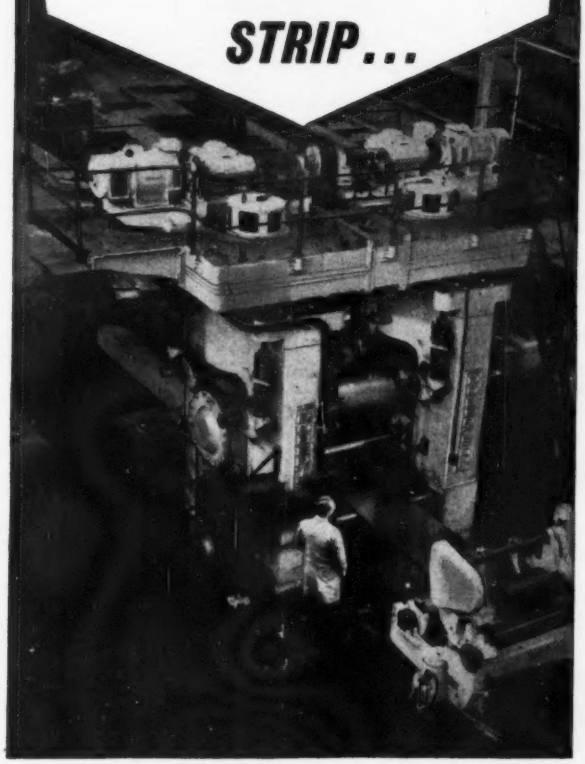

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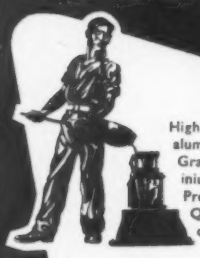
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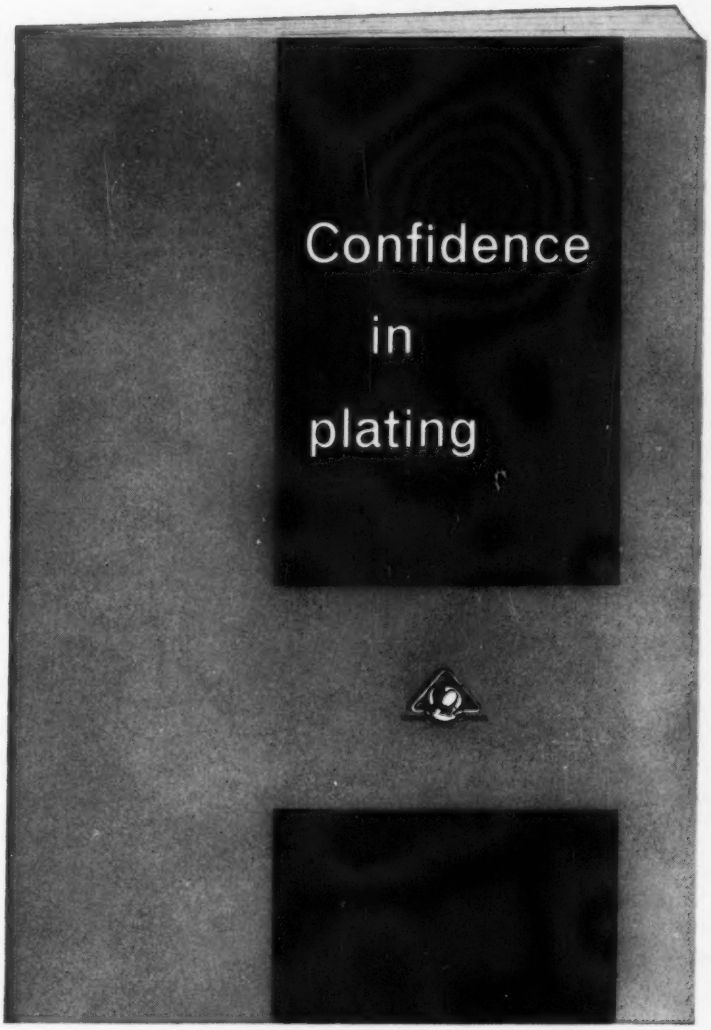

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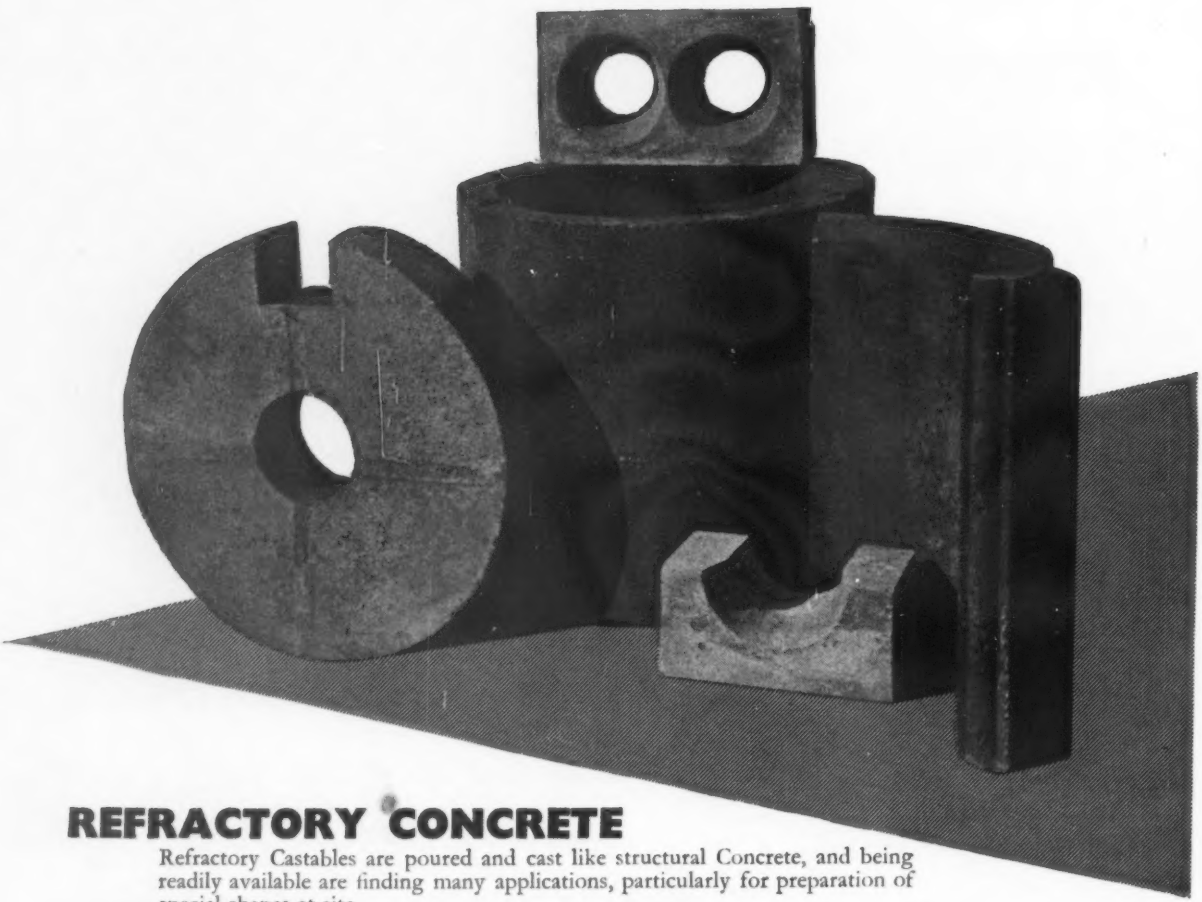

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METAL INDUSTRY

FOUNDED 1909

EDITOR: L. G. BERESFORD, B.Sc., F.I.M.

4 DECEMBER 1959 VOLUME 95 NUMBER 17

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Hailsham

METAL INDUSTRY 1909-1959

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" . . . I should like to add my congratulations to the many that you will no doubt receive in connection with your Golden Jubilee. In my company your publication has been read for over forty years to my personal knowledge and we would like to record our appreciation of the high standard of your technical articles . . . "

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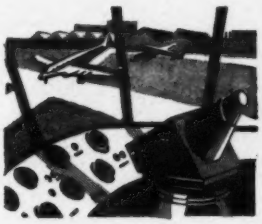
1909 - 1959

NON-FERROUS METALS IN THE



Aircraft Industry

by MAJOR P. L. TEED, O.B.E.
A.R.S.M., M.I.M.M., F.R.Ae.S., F.I.M., F.R.S.A.

Deputy Chief of Department of Aeronautical Research and Development Vickers-Armstrongs (Aircraft) Limited.

IN discharging the obligation implied by the title of this article, the author has to survey the past and to foretell the future. Alive alike to the difficulties of his task and to his own limitations, prologue-like, he craves indulgence. Those more erudite than himself will at once correct his errors as to what has been. His wrong evaluation of what is to be cannot, however, be subjected to such prompt exposure. An interlude must elapse to allow of the future becoming the present and then the past.

Powered flight developed along three different lines, one of which gave rise to the rigid airship, the structure of which owed so much to a then new non-ferrous alloy, Duralumin, possessing the novel, though even at that time, not unique, property of age-hardening.

While in Europe the airship was beginning to evolve on what seemed to be rewarding lines, on the other side of the Atlantic the brothers Wright succeeded in building and flying a heavier-than-air machine. This was based on the study of bird flight yet, in form, it in no way disclosed to the uninitiated its ornithological mentor. The machine was, in fact, described by one of their fellow countrymen as "a stick and string box-kite with a gasoline buggy engine", and there was a measure of truth in this. Somewhat surprisingly, the great feat was accomplished virtually without the aid of non-ferrous metals. None was employed in the airframe. In the engine, of twelve doubtful horse power, an aluminium-copper alloy was used for its cylinder block and crankcase.

From the Wright's splendid pioneering effort until the outbreak of the First World War, some 5,000 aeroplanes were built, mainly in France and Germany. In the same period, Great Britain, rather in accordance with tradition, was a reluctant starter. During the conflict, however, about a quarter of a million airframes were produced. This country alone, feverishly making up for lost time, contributed some 55,000. The engines of these craft admittedly contained a substantial proportion of non-ferrous metal, chiefly in the form of aluminium alloy castings, but their airframes with one or two exceptions, of which the Fokker was the most notable (it had a welded steel tube structure), were of "stick and string". This slick American phrase means of wood, with welded mild steel attachments and wire bracing. Thus, while the airframe of the period (and, indeed, with trifling exceptions, up to about 1920) was virtually without non-ferrous alloys, the contemporary rigid airship (in German hands, for a time, a formidable weapon) generally possessed an elaborate Duralumin structure. This apparent paradox requires some explanation.

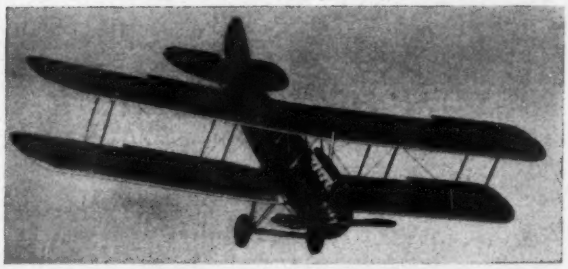
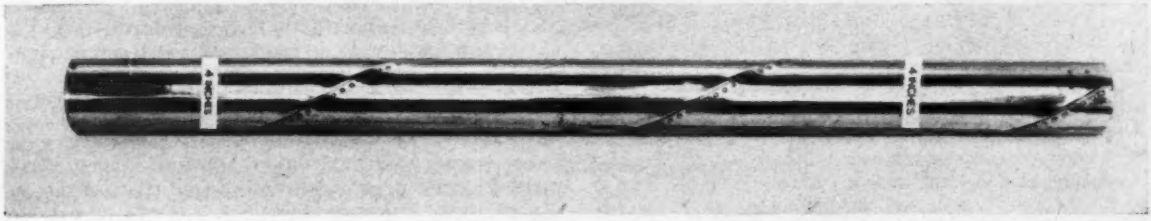


Fig. 1—Short "Silver Streak". All-up-weight 2870 lb. Span 37·5 ft. Engine 230 h.p. Siddeley Puma. Speed 125 miles per hour. (Courtesy Short Bros. & Harland)

Roughly speaking, the designer of airframes has as his object the production of the lightest possible unit which possesses the requisite strength to perform its functions. To do this, he cannot, in general, use a single material for the whole structure. The necessity for diversity arises from the fact that the character and magnitude of the loads imposed are themselves diversified. Were airframe stresses entirely tension ones, such as they are in a gas cylinder, then the problem would be seemingly simple. The material whose ultimate tensile stress divided by its specific gravity gave the largest quotient should, on the assumption made, give the lightest product. On the basis of strict logic, the pressure vessel maker would thus be faced with producing what was required from mica, and if he went on strike, who would blame him?

Under static loads, compressive stresses create the structural designer's most difficult problem. It is not one, however, which can be here examined. The position can, however, be stated in a trite generalization—to meet the object in view, light compressive loads can best be resisted by light materials, but for heavy ones, their employment is,

*Fig. 2—Four inch diameter, 18 S.W.G. tube made rom Duralumin strip and used in the construction of Rigid Airship R.*100. *(Courtesy Vickers-Armstrongs (Aircraft) Ltd.)*



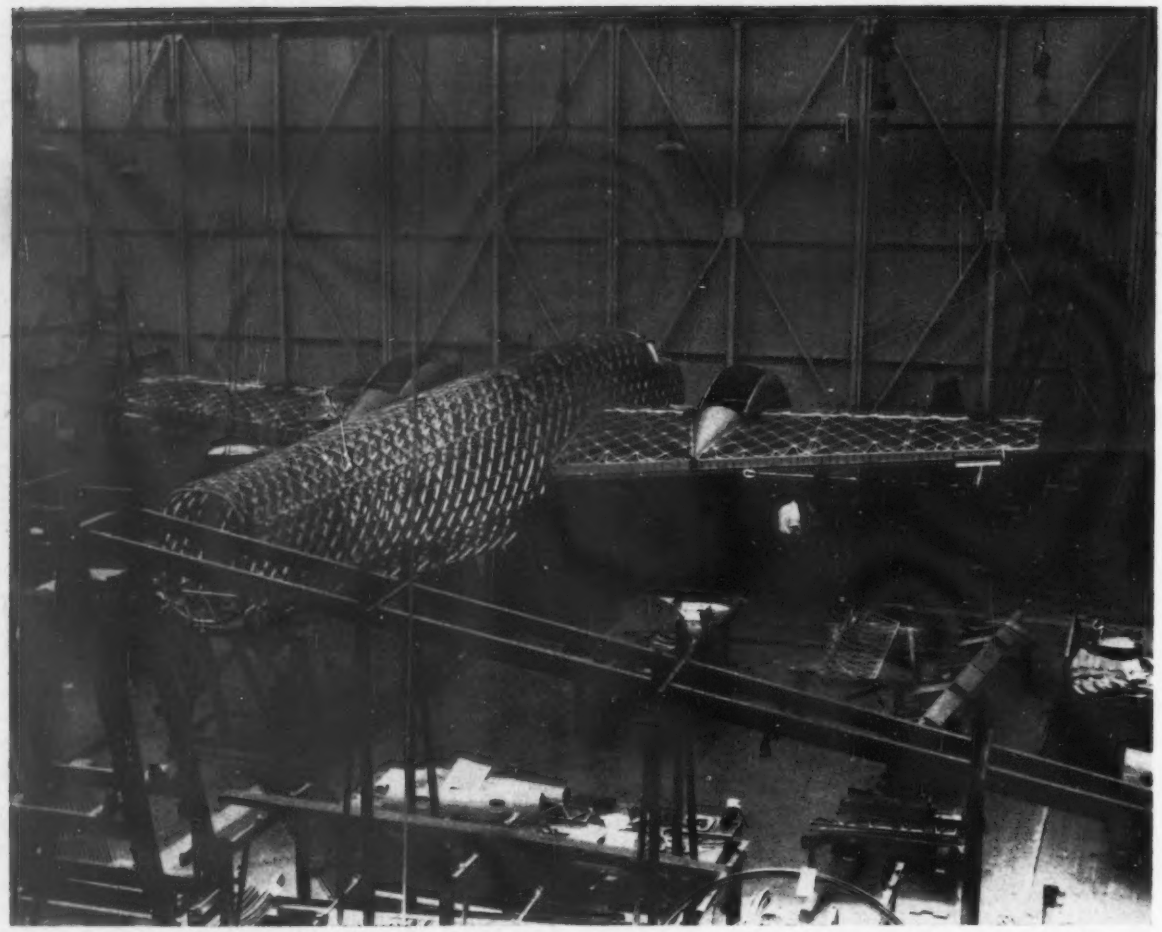


Fig. 3—Vickers "Wellington" bomber. All-up-weight, depending on Mark, 25,000-31,000 lb. Span 86 ft. 2 in. Engines Pegasus or Hercules

by no means, imperative and may be disadvantageous, certainly where volume has to be taken into consideration. Were an aircraft structural engineer of today asked to redesign the Wright machine of 1903, he might well employ wood for the interplane struts and for some other parts.

After the Treaty of Versailles it was thought, in Government circles, and in the light of history, rightly thought, that no major war would take place for at least a decade. The finances of all former belligerent states had, naturally enough, been greatly depleted; the making of munitions, and at this time the aeroplane was officially regarded purely as a munition, had also been almost halted. On the other hand, the rigid airship was, for a period extending to about 1931, believed to have commercial possibilities worthy of Government support. Its speed was vastly greater than that of even the largest ocean liners, while its endurance was such that it could seemingly traverse the same routes, thus promising much quicker mail and passenger travel.

Such craft, within the period under review, were built in this country, Germany and in the United States. In all but one case, their designers employed Duralumin for their primary structure. This fact was significant: by the time this lighter-than-air experiment was completed, there existed a body of structural engineers and craftsmen well familiar with design and fabrication in an alloy which, earlier, had been regarded as being not wholly innocent of black magic.

Another, and in some ways a stronger, influence leading to the extensive use of wrought aluminium alloys in aeroplane structures was due to the Air Council. In the early years of peace, this body, reviewing the past in the hope of being prepared for the future, was much impressed by the almost complete absence in this country of indigenous timbers then regarded as essential for aircraft construction. It was therefore laid down that in military types of machine, such structures must be of metal. Aircraft engineers, of course, adopted this decision but, in its application they were not initially of one mind. Some designed largely in alloy steel strip but, by 1939, the use for this purpose of age-hardening aluminium alloy had become almost universal.

The non-aeronautical, non-ferrous metallurgist may feel that from the time of their becoming available in adequate quantities, the triumph of wrought aluminium alloys for aircraft structures was not only pre-destined, but likely to be precipitate. The writer, while appreciating this train of thought, believes that the change took place when it did, largely because of the non-technical logistic decision of the Air Council. In aircraft of the size in use up to at least the beginning of the Second World War, the reduction gained in structural weight, due to the use of such alloys, was relatively small.

That a quite first class military aircraft could be made, using a considerable amount of wood for structural purposes, was clearly shown, even during the Second World War, by the production of the "Mosquito". The fabrication of this machine, violating as it did the earlier decision of the Air Council was, nevertheless, justified in every respect. It

was an aircraft of great military worth and, due to the ingenuity of the designer, involved a unique form of construction which made small demand for long lengths of timber of aeronautical grade. Further, and very importantly, making it gave employment to men and tools not otherwise occupied in munition manufacture.

The non-ferrous metallurgist, thinking of this wood-light alloy battle, may yet feel it was unduly long. The aircraft engineer making his valedictory address to aircraft timber as a structural material, should certainly have given grateful thanks for its low density, relatively high specific Young's modulus, fatigue endurance and very high notch fatigue endurance. The writer, having participated in the felling of beautiful spruce trees on the Pacific Coast that aircraft spars might be made and knowing such cutting still goes on, is sad to think that the resulting wood will probably be used for nothing more inspiring than the sides of step-ladders.

From the Wright's first flight to the end of the Second World War, the speed of aircraft had increased some ten miles per hour per annum, but was still subsonic. Their all-up-weight at take-off had grown from 750 lb. to about 70,000 lb. Range had become sufficient to allow of crossing the Atlantic with safety. The height record was over 70,000 ft., but pressurization of the interior of aircraft had not become standard practice so, without oxygen and its attendant complexities, one generally flew below, rather than above, the weather. Airframes, with few exceptions, were made of wrought light alloy. Aero engines, in general, were, by weight, rather less than 50 per cent non-ferrous. A horse-power was developed for slightly under one pound in weight and from rather less than one cubic inch of swept volume: in fact, very, very great things had been done. It would, however, be invidious were the writer to praise famous men. He will, nevertheless, give a few examples of their fine work.

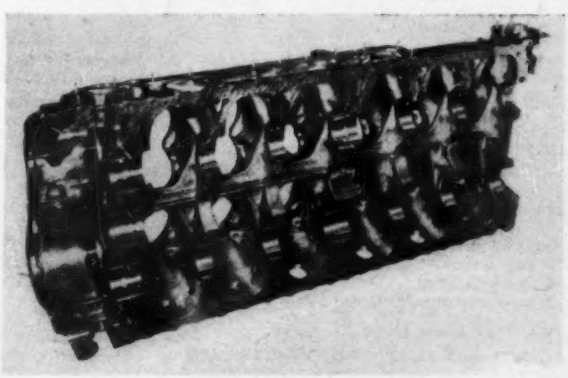
The illustration (Fig. 1) shows the Short "Silver Streak". This machine of 1920 was one of the first to be built almost entirely of wrought aluminium alloy. A portion of a four inch diameter tube of 18 S.W.G., such as was most extensively used in the structure of the very successful rigid airship, R.100, is shown in Fig. 2. It will be noted that the method of manufacture employed was novel. It was, in fact, made from joggled Duralumin strip, wound at an angle on to a mandrel and then riveted. This method had to be especially developed, for, in the period 1925-30, as would indeed be the case now, it was not possible to extrude a tube of the necessary length, having anything approaching the diameter: thickness ratio required. Tubes of lighter gauge, of three inches in diameter and up to 70 feet long, were produced by this ingenious method. The famous "Wellington" bomber, of which over 11,000 were, in all, built, is depicted in Fig. 3. Its structure was largely geodetic and, as a consequence of this, it had a low structural weight. Further, because of the multiplicity of its components, it was quite remarkable in standing up to damage inflicted by the enemy. The curved members, or geodices, were all formed from Duralumin strip. A forging of the front portion of a "Centaurus" crankcase is shown in Fig. 4, while Fig. 5 shows another part of a crankcase, in this instance, a casting of the "Sabre" engine. This fine example of the combined skills of designer and founder contained between 35 and 40 cores. The casting was of a precipitation treated aluminium-copper-nickel alloy and, after fettling, weighed 119 lb.

By 1945, the war was won. On the air side, this can be rightly attributed to two superiorities, personnel and material. The aircraft used, were, in the main, piston engined. Their airframes were generally of wrought aluminium alloy, sometimes covered with linen fabric. Naturally enough, during the period of hostilities, civil aviation, certainly as far as development was concerned, was moribund. With peace, however, it speedily became re-vitalized. More than one cause led to the virtual abandonment of fabric covering. Airline operators found it difficult to maintain and were prepared, even should this involve the loss of some disposable load, to have it replaced by light alloy sheet. An additional and stronger influence in this direction arose from competitive pressures leading to a continuing demand for increased speeds. This soon made organic coverings largely unsuitable. In flight, such surfaces tended to be unstable and to increase drag. Further, somewhat later, but with even more compelling force, metal covering became essential, if civil aircraft were to be extensively patronized by those who normally, because of sickness, feared to travel by sea.

The graph, Fig. 6, shows on a numerical basis, what had been known, in generalized terms, from almost the start of free-ballooning, some century and a half ago, namely that except in thundery weather, with increase in height the atmosphere becomes less turbulent. From the graph, it will be seen that, when flying at 5,000 ft., a gust of 10 ft/sec. or more is, on the average, encountered every 18 miles. At 20,000 ft., the gust frequency is only about a twentieth of this, while at 40,000 ft., it is but one-hundredth. These figures, from the point of view of passenger comfort, become more impressive if the frequency of the gusts is expressed in time rather than in distance. When travelling at an airspeed of 300 m.p.h., a gust of the magnitude stated is encountered once every 3·6 min.: at 20,000 ft. the time

Fig. 4—Portion of the crankcase of the Bristol "Centaurus" engine, forged in Hiduminium R.R.56 (B.S. 2L40). Weight of component 147 lb. and outside diameter 30 in. (Courtesy High Duty Alloys Ltd.)

Fig. 5—Portion of the crankcase of the Napier "Sabre" engine, sandcast in D.T.D. 133 or D.T.D. 287. 35—40 cores were used to make this casting. Fettled weight 119 lb. (Courtesy D. Napier & Son Ltd.)



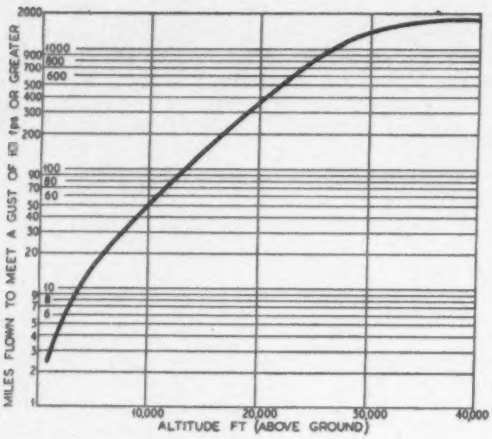


Fig. 6—Variation of gust frequency with altitude

interval becomes 70 min., and at 40,000 ft. it is 6 hr. This provides a weighty reason for flying high, an achievement facilitated by the availability of the gas turbine engine. This could not, however, be carried out in civil aircraft in a satisfactory manner without considerable modification of the fuselage. The relationship of air density to height is shown in Fig. 7. Then, when it is added that the elderly and many who are not yet elderly, find the atmosphere, even as low as 10,000 ft. distressing to breathe, it is clear that the passenger appeal advantages of flying high can only be obtained if the density of the air within the fuselage is not distressing to those travelling in it. To do this demands pressurization. This, designers have met by making a light alloy pressure-tight shell an essential feature of their structures.

In War, there are, of course, obvious advantages to be gained by flying high. In Peace, as has just been explained, altitude also has much to commend it. The gain, however, is not without its price. Flying high has made a transcendental contribution to the potentialities of civil aviation and a lesser one to the volume of light alloy sales. It was not adopted without careful consideration. The technical reason for such doubt as did exist is revealed in Fig. 8. With increase in altitude, there is a decrease in the temperature of the atmosphere, so, when airspeeds were subsonic, as they still are in civil aircraft, the influence of such temperatures on the mechanical properties of all aircraft structural materials had to be intensively studied. This, while revealing at stratospheric temperatures, certain disturbing features, particularly with regard to the properties of carbon and chromium steels, has been wholly reassuring as to both the static and dynamic behaviour of cast and wrought aluminium alloys.

Table I—Materials in Subsonic Aircraft

Material and Form	Weight as Percentage of Total Structure Weight			
	Aircraft "A"		Aircraft "B"	
Aluminium Alloys				
Sheet and strip	44·0		58·7	
Bars and sections	28·0		18·3	
Tubes	2·0		1·4	
Castings and Forgings	2·0		2·4	
		76·0		80·8
Ferrous Alloys				
All Forms		8·0		17·0
Magnesium Alloys				
All Forms		3·0		0·3
Copper Alloys		1·0		0·7
Miscellaneous Materials				
All Forms		12·0		1·2
		100·0		100·0

The development from the Wright machine to current types has, of course, involved quite enormous changes in size, shape and materials of construction. Today, two justly famous subsonic aircraft, each of about 80,000 lb. basic weight (roughly equivalent to tare weight), have airframes made of materials in the proportions stated in Table I.

Both machines are thus about three-quarters wrought aluminium alloy and approximately 80 per cent non-ferrous metals; but what of tomorrow? The answer depends on how one is going to take off and how fast and how far one wishes to fly. At the present time there are the following types of aircraft in use:

(1) Subsonic machines capable of hovering flight, like the helicopter.
(2) Subsonic low-level very long range sea reconnaissance craft.
(3) Subsonic bombers of varying range.
(4) Subsonic fighters, interceptors, etc.
(5) Subsonic transports of medium range.
(6) Subsonic transports of long range (about 4,000 miles).
(7) Supersonic fighters.
(8) Supersonic bombers.
(9) Supersonic transports.
(10) Supersonic machines capable of hovering flight, like the coleopter.

Classes (1) to (6), that is to say, all the machines whose speed at ground level does not exceed 760 m.p.h. (or 660 in the stratosphere) are very largely made of wrought aluminium alloys. So they will continue to be unless, and this is difficult to imagine, there comes into being a better structural material for the purpose. As to supersonic machines, at present very few in number, it is not possible to speak with the same measure of conviction. The physical, mechanical and metallurgical implications of the problem are well understood. What is obscure is the answer to the question: "How supersonic does man want to fly?" or perhaps better: "How small and insignificant does he wish to make his world. Will he stand for its being reduced to the size of a parish?"

Turning for the moment to the vast majority of the machines of the present, namely the subsonic ones: these provide a ready outlet for wrought aluminium alloys and for a lesser quantity of other non-ferrous metals; but are they likely to be able to do this in the future? On technical grounds, such alloys have met and continue to meet aircraft designers' requirements, but will such machines continue to be built? Machines having a performance akin to that of a helicopter, both in war and peace, have most definite roles.

As to the more conventional military aircraft, the Ministry of Defence White Paper of 1957 appears to regard them as discharging functions soon capable of being better done by other means. This truth, if it is, in fact, a truth, seems to be of limited application. Some subsonic military aircraft, capable of dropping anything from a hint to a bomb, will for many years to come, constitute a useful constituent of the armed forces. Further, inter-city, as opposed to intercontinental, civil aircraft, are expected long to continue to be subsonic.

While the metallurgical problem imposed by high altitude subsonic flight was the influence of stratospheric cold on the mechanical properties of the structural materials of which aircraft were made, the corresponding supersonic flight one is the heat engendered by the speed of the machine through the ambient atmosphere. This relationship under a variety of conditions is shown in Fig. 9. Curve C probably provides the most realistic guidance as to what has to be faced.

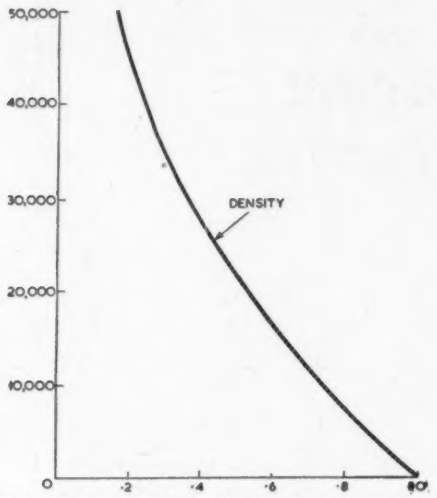


Fig. 7—Variation of atmospheric density in the temperate zone with height in feet above sea level

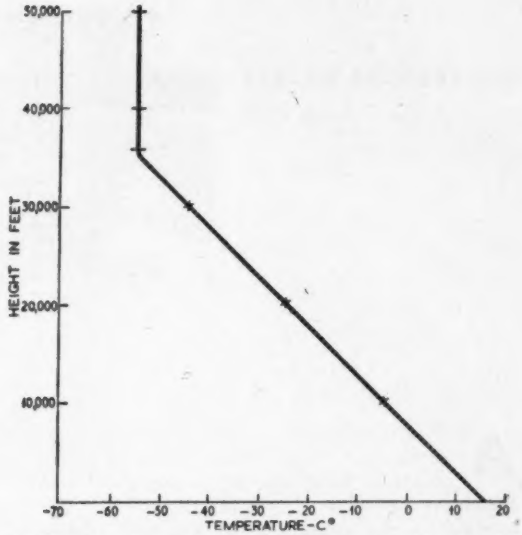


Fig. 8—Variation of atmospheric temperature in the temperate zone with height above sea level

From it, it will be seen that at twice the velocity of sound, 1,320 m.p.h., the temperature of the exposed surfaces of the aircraft will be about 100°C. Aluminium alloys of a modified Duralumin type, though temporarily somewhat weakened by such a temperature, undergo no serious deleterious change. At three times the sonic velocity, which is about 2,000 m.p.h., the airframe will be at about 200°C. At this temperature all at present known age-hardening aluminium alloys are not only seriously weakened, but undergo a permanent and considerable loss in mechanical properties. Thus, while airspeeds remain somewhat below two and a quarter times the sonic velocity (about 1,500 m.p.h.) light alloys can continue to be used for airframe construction; what is to be employed above this speed calls for serious consideration.

Material for aircraft structures is not selected either on the spin of a coin or because of some unique property it is alleged to possess. The aircraft designer, to make this choice, has to know in concrete terms, over a wide range of temperature, of the following qualities of possible structural alloys:

(a) Specific gravity.

(b) Limit of proportionality in tension and compression; 0·1 per cent proof stress in tension and compression; ultimate stress in tension and compression.

(c) Hardness; rubbing qualities.

(d) Yield stress in torsion.

(e) Pin shear yield stress; pin shear ultimate stress.

(f) Elongation; reduction of area.

(g) Notched bar impact resistance.

(h) Fatigue limit; notched fatigue limit; corrosion fatigue characteristics.

(i) Creep characteristics.

(j) Young's modulus; tangent modulus; shear modulus; bulk modulus; Poisson's ratio.

(k) Coefficient of expansion and thermal conductivity.

Then, offsetting one consideration with another, he makes his decision. This, for the last forty years in all countries and for all aircraft other than the very smallest, has almost always resulted in some kind of age-hardening aluminium alloy being selected for the major portion of his structure. From Fig. 9, however, it would seem that for machines having a speed of over 1,500 m.p.h. their long enduring monopoly has been broken.

The reader, initially, may be unwilling to accept this dictum. He may suggest that if means, such as refrigeration or insulation of the structure were employed, no change in

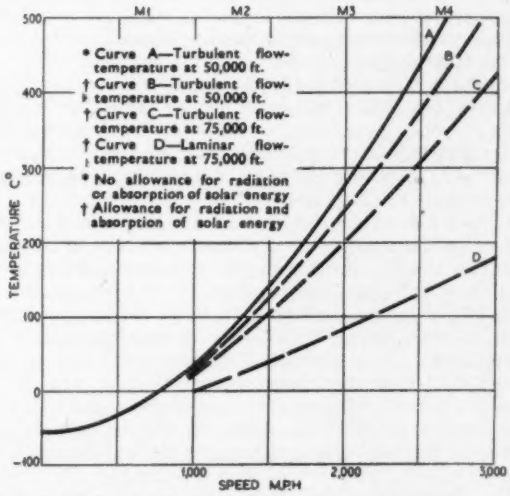


Fig. 9—Relationship between speed and surface temperature of aircraft (after A. A. Hall)

the material of construction would be necessary. An appraisal as to what would be required in terms of power to meet the first suggestion has been made. The unweighted and impartial answer is more than discouraging. As to insulation, it is believed, no practical solution yet exists, but research may reveal one. Failing this, a change in materials must be made. For speeds of about 1,500 to 2,500 m.p.h, a titanium alloy might, after its design and fabrication techniques had been mastered, meet the case. At still higher speeds some type of non-oxidizing alloy steel could provide a solution, no doubt at considerable cost in terms of weight. These matters are for the future.

To end on a sincere but not an optimistic note; if, as is currently foretold by American prophets, the speed of medium and long range aircraft is raised, within the next ten to fifteen years, to three times the sonic velocity (about 2,000 m.p.h.), not only will non-ferrous alloys, with the possible exception of those of titanium, be virtually absent from such machines but, unless there is a corresponding increase in the number of air travellers, markedly fewer civil aircraft will be required.

1909 - 1959

NON-FERROUS METALS IN THE

Marine Industry

by S. F. DOREY, C.B.E.
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Former Chief Engineer Surveyor of Lloyds Register of Shipping

AT the end of the last century a considerable diminution in the use of non-ferrous metals took place in the marine industry, due to the changeover from wood and composite ships to iron and steel ships. The general adoption of the steam turbine machinery, particularly in warships some 50 years ago, also caused the percentage of non-ferrous metals to fall from about 34 per cent to 17 per cent of that of the combined iron and steel used in the machinery. In the case of the hull structures the non-ferrous metal content at this time was about 4½ per cent of the total weight.

At the commencement of the period under review, the principal non-ferrous metals in general use in the marine industry were copper, brass, gunmetal, lead and white metal. A certain amount of aluminium was used in the form of small plates for unimportant structures and aluminium bronzes were being tried out.

Copper was used principally by the marine engineer for steam and other pipes, possessing the qualities of ductility and resistance to corrosion. Copper-zinc alloys were used for propellers and large ships' castings, brass condenser tubes, tube plates and condenser shells, brass bolts, pump rods, valve spindles, turbine blades, packings and occasionally for small screwshafts. Muntz metal (60 copper-40 zinc) was still used for the sheathing of ships' bottoms having good general strength and ductility with ability to resist corrosive action of sea water though liable to be affected through galvanic action. Lead was used mainly for bilge and ballast pump suction pipes. White metal was naturally used for bearings, its composition depending on its use whether with light or heavy loads with oil lubrication and propeller shaft bearings running in sea water without oil, while of alloys containing copper, tin and antimony used for stern shaft bearings and the main bearings of the propelling machinery, there were numerous brands produced each claiming special qualities.

Pure aluminium of the best quality was used in ship-building in partitions, ceilings, some decks and chart houses, and where reduction of top weight was of importance in connection with the stability of the vessel as, for example, in very high powered small vessels like torpedo boats; but the supply position for sheets was difficult. It is significant to note that the total annual production of aluminium in 1909 was about 30,000 tons compared with the present annual output of over 3,000,000 tons.

So-called aluminium bronzes produced by the addition of aluminium to electrolytic copper in quantities up to 10 per cent were used for marine purposes but were subject to rapid corrosion when used under sea water. With additions of 5 to 6 per cent, and even up to 10 per cent aluminium to normal bronze of copper, tin and zinc alloy, the corrosive effect was very slight.

Although these metals and alloys were used abundantly it was found that while strength and ductility were often considered paramount by the manufacturer, the materials failed under special conditions of treatment and use, and were, so far as normal conditions were concerned, unsuitable

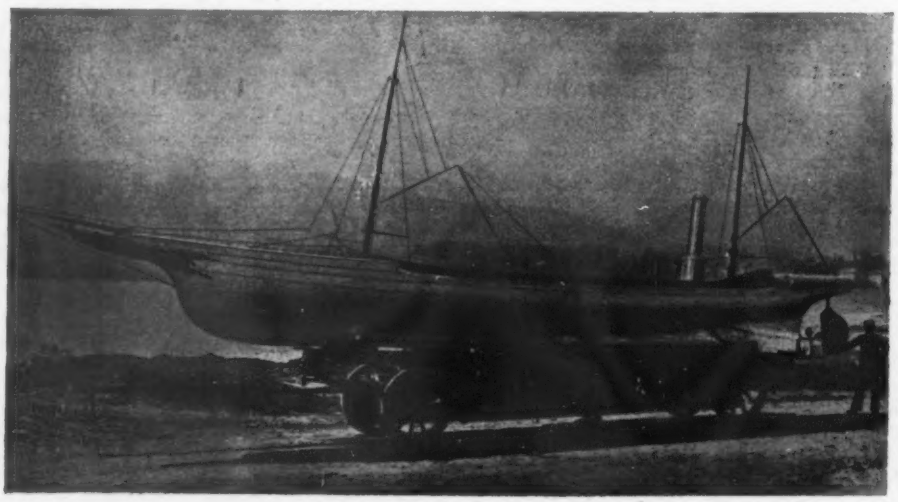


Fig. 1—The "Mignon". A Swiss aluminium boat built in 1892. (Courtesy A.I.A.G.)

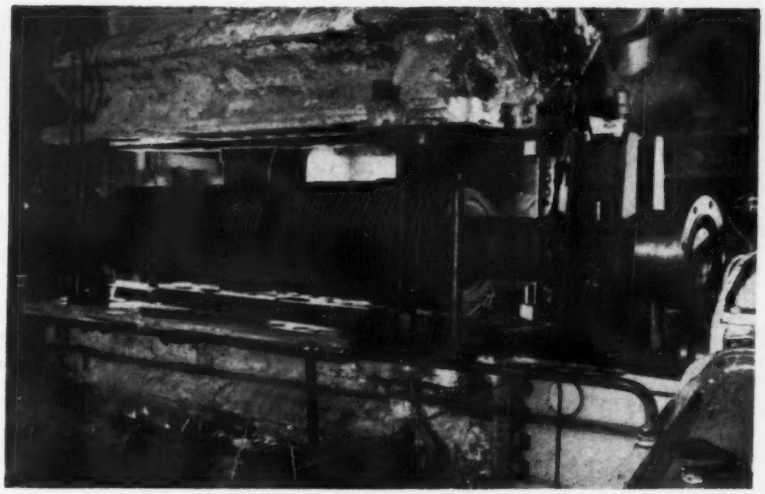


Fig. 2—H.P. port turbine on the P & O SS. "Carthage" showing the condition of the original Monel blading after 25 years of service. (Courtesy The Mond Nickel Co. Ltd.)

for long continued exposure to the action of sea water. This was conspicuous in the case of aluminium and its alloys, which at first gave great promise for the future and long delayed their acceptance. Yet it could not be said at that time that the other commonly used metals were free from their troubles, copper being a case in point which could be adversely affected by improper cold work and annealing, and also by small quantities of bismuth, while gunmetal, white metal and other alloys had their properties affected by the temperature when pouring the metal, the rate of cooling and the temperature of the bearing into which the metal was poured.

It was evident there was a lack of scientific precision and knowledge in melting, mixing and pouring of metals, and with the increasing demands for materials to withstand more arduous conditions, coupled with a desire to reduce factors of safety for economical as well as weight saving reasons, scientific methods and research had to be reduced to the practical form to enable the manufacturer and user to reap full benefit in the development of metals and their alloys with specific qualities. By 1920 a decided change had taken place in the use of non-ferrous metals, particularly with naval machinery. Copper steam pipes had disappeared and been replaced by steel and gunmetal for condenser ends and shells had been replaced by cast iron and sheet steel with improvement in the life of condenser tubes. Copper had also been replaced by steel for feed discharge pipes and fire service pipes, and gunmetal became unserviceable with increase of steam temperatures. Although failures in condenser tubes had been reduced considerably there was still much room for improvement, since failures became a serious drawback to the efficiency of the Fleet, and it became obvious that an alloy better than a simple brass was required.

Bronzes with improved qualities were still in use, such as phosphor bronze castings, some containing 15 per cent and others 10 per cent phosphorus, and with addition of small percentages of lead suitable for bearings: also in sheets for air pump valves and in wire for electrical purposes: manganese bronzes for castings and especially propeller blades having a tensile strength up to 30-35 tons/in^2 being less liable to corrode than steel and giving a good surface important to the fast ships having high speeds of rotation: high strength alloys of copper and zinc plus iron and also tin, aluminium, manganese or nickel, such as Delta metal. With the introduction of the impulse turbine and increase of superheat temperature (about 100°F.), brass blades were no longer satisfactory and were replaced by phosphor bronze at the high pressure end. Monel metal was tried out but manufacturing and supply difficulties at this time could not be overcome and experiments were also carried out with cast aluminium bronze. Considerable improvement had also been made in bearing metals, largely due to the problems of lubrication being better understood and applied, Reynold's work and that of Michell having given a practical solution in no uncertain manner.

The oil engine was also being rapidly developed for marine purposes with the adoption of pistons of aluminium alloys and piston rings of copper-zinc alloys.

In the next ten years with the advantage of intensive research and development an increasing number of new alloys were produced, together with a large variety of alloy steels brought about by higher steam temperatures than previously used, the increase in number, size and speed of oil engines, and through the troubles experienced in the service behaviour of certain parts of machinery. It is only right to mention experience showed that design could be at fault often through an incomplete knowledge of the complex stress distribution and temperatures under actual working conditions. Knowledge was, however, being accumulated of the fatigue properties of materials under repeated stresses in environments of air, fresh water and sea water, and also of the creep strength at high temperatures of a number of engineering metals. Condenser tubes were still a matter for investigation although there was a better understanding of the causes of failure. Experiments were carried out with tubes made of stainless steel, Monel metal, aluminium brass, 80 copper-20 nickel, 70 copper-30 nickel, chromium-coated Admiralty brass tubes, Silveroid and a few others, and of these Monel metal and aluminium brass were found to be the most satisfactory. The former became generally used in naval condensers while aluminium brass, due to its cheapness compared with Monel metal, became generally adopted in turbine engined ships of the mercantile marine. Improved alloys were used for turbine blading and specifications and inspection became more stringent. Stainless iron and steel were employed in H.P. turbines, also Monel and phosphor bronze in all stages. Brass was still employed for reaction blades, only electrolytic copper and zinc of 99·75 per cent purity being used, the brass blading being annealed at an approved temperature. For a number of general castings a copper-silicon alloy known as P.M.G., containing 3-4 per cent silicon, came into use as a substitute for Admiralty gunmetal with a saving in both price and weight.

Fig. 3—Hayward Tyler centrifugal pump casting

In these ten years, the use of aluminium and aluminium alloys in naval ships increased from the experimental stage to tons in a cruiser, largely for weight saving purposes since the corrosion problem still remained. A number of aluminium-silicon alloys were produced giving better service, and "Y" alloy used for naval oil engine pistons and other high speed engines continued to give very satisfactory results.

Mention should also be made of the use of nickel, cadmium and chromium for electrodeposition, as in the "Fescolising" process for coating condenser tubes, working parts of steam expansion glands and damaged and worn turbine rotor shafts and wheels.

Increasing quantities of non-ferrous metals were now being used to form special alloys of steel, amongst the more important being nickel, chromium, molybdenum, tungsten and vanadium. Nickel in small percentages was also being used to improve the structure and quality of cast iron.

The Present Position

In present-day marine engineering the proportion of non-ferrous metals employed in relation to other materials is still relatively small; nevertheless recent developments and improvements have increased the number and types of alloys in service in addition to widening their field of application, thus serving a most vital role in ensuring efficient operation and adequate service life of machinery and structures.

The continued use and future possibilities of non-ferrous metals in the marine industry depend essentially on the special characteristics possessed by these metals and alloys, and in consequence the total weight alone used in any ship is not necessarily an indication of their prime importance. Nevertheless, some information respecting the tonnage used may not be out of place, and the following figures give an indication of their trend in the machinery of some ships, commencing with the passenger liner T.S.S. *Olympic* of 46,400 tons gross built by Harland & Wolff in 1911 and fitted with twin steam reciprocating engines and an L.P. turbine on the centre shaft, developing a total of 51,000 h.p.

Olympic. Total weight of non-ferrous metals 635 tons, of which the main engines took 220 tons, propellers 62 tons, copper and brass pipes 173 tons. The weight of the brass tubes in the condensers was 51 tons with a further 10 tons for the tube plates, the brass blades in the L.P. turbine weighed about 50 tons, while the zinc plates fitted in the Scotch boilers as an anti-corrosion measure amounted to about 7 tons.

Three cargo vessels of about 10,000 tons deadweight (say, 18,000 tons gross) built about 1928 and fitted with (1) steam reciprocating engines, (2) steam turbines, (3) diesel engines, all developing about 6,000 h.p. The weights of non-ferrous metals used in the machinery only (boiler, etc., not included) were (1) 7·7 tons, (2) 4·4 tons, (3) 62 tons (includes main engines, auxiliary engines and other fittings). These ships each had about 30 miles of electric cables weighing 30 tons, and the 20 electric winches with their motors contained 15 tons of copper and 1 ton of phosphor bronze, gunmetal, etc.

Pretoria Castle (1948), passenger liner of 28,700 tons gross and 35,000 s.h.p. twin screw D.R. geared steam turbines, approximate weight of non-ferrous metals in the machinery installation, 242 tons rough weight.

Bloemfontein Castle (1949), cargo liner of 18,400 tons gross and 16,000 s.h.p.; diesel engine machinery has about 118 tons rough weight of non-ferrous metals.

The weight of copper used for the electric cables in a ship is also of some significance considering the miles of cables installed, and may reach 25 to 50 tons and much more in the larger passenger vessels. There are 230 miles of cables in *Pretoria Castle* and 125 miles in *Bloemfontein Castle*, while the total weights of copper for all purposes, including motors, cables, etc., amount to 65 tons and 38 tons respectively. The *Queen Mary* has about 738 miles of electric cable.

Turbines

The high temperatures required for the efficient performance of gas turbines naturally focused attention on the need for superior materials, and in this country the well-tried Nimonic series of alloys, ferric and austenitic steels have given good results, while in the U.S.A. a more extensive use has been made of cobalt-base alloys. It is remarkable how important a part has been played by the employment of non-ferrous metals in both heat- and creep-resisting steels containing high contents of nickel, chromium, cobalt, molybdenum, titanium, niobium, tungsten and manganese, the total contents of which frequently exceed 45 per cent. For gas-turbine blading and nozzles, alloys have been based on nickel-chromium-iron and nickel-cobalt-iron, Nimonic alloys being almost exclusively used, and for still higher temperatures chromium, titanium and molybdenum are the metals mainly used in alloys, a typical example being 60 per cent chromium, 25 per cent molybdenum and 15 per cent iron.

In steam turbines ferrous alloys have almost completely replaced non-ferrous alloys, stainless iron and nickel-chromium, ferritic and austenitic steel being most commonly used. For gland purposes the most suitable alloys are brass up to 850°F., S. Monel (3·5 per cent silicon) leaded nickel bronze below 1,300°F. and Nimonic 75 and 80A for higher temperatures, although no marine turbine has yet been designed for working at temperatures above 1,050°F.

Oil Engines

In high speed engines, cast aluminium-alloy pistons and skirts, of "Y" alloy and R.R. alloys, have been largely used due to the advantage of reduction in reciprocating masses. In other respects cast aluminium alloys containing silicon and magnesium have little scope in the engine rooms of the mercantile marine with the exception of crankcase doors for ease of handling, and other structural members of engines where weight is a consideration. Chromium is used as a deposit on the wearing surfaces of oil engine liners, and more recently in the U.S.A. hot dip aluminizing of large piston heads, piston rings and exhaust valves has considerably reduced wear and erosion. An alloy of 75Ni-15Cr-5Fe-5B has also been used on cast and forged steel piston heads.

Bearings

The suitability of a bearing depends entirely on its service conditions and no ideal alloy exists. The various characteristics required are low coefficient of friction, high resistance to local seizure, adequate mechanical strength at operating temperatures, and sufficient tolerance to withstand normal amounts of misalignment, low rates of wear and high corrosion-resistance. Non-ferrous metals and alloys have played a most important function through having all or a combination of these qualities, though much will also depend on mechanical features such as bearing dimension, clearance, surface condition and lubrication characteristics.

In practice, bearings are either of the thin- or thick-shelled type. In oil engine practice the shell thicknesses for main bearings vary from $\frac{1}{16}$ in. to $\frac{1}{2}$ in. at a journal diameter of 24 in. to $\frac{1}{32}$ in. to $\frac{1}{2}$ in. for small diameter shafts. As most marine engine shafting is of normalized plain carbon steel, white metal bearings of the high-tin Babbitt types containing 80-93 per cent tin are employed. High speed engines with increased bearing loads employ thick-shelled lead bronze, tin-backed to steel. Aluminium-20 per cent tin alloy and 30:30:40 copper-silver-lead alloy with superior fatigue properties are also being used and some high speed heavy oil engines use silver for bearing liners.

For lightly loaded bearings for line shafting lead-base Babbitt's metal gives excellent service. Top end bearings are made of white metal, lead-bronze and phosphor-bronze bushes. Similar materials are used in pumps whilst for underwater service an alloy of zinc 30 per cent, tin 68 per cent and copper 2 per cent is frequently preferred.

Propeller shafts working in stern tubes and brackets are usually fitted with gunmetal liners within the range 88:10:2 or 87:8:5 or leaded gunmetals of the 85:5:5:5 type.

Condensers

Arsenic-bearing 70:30 brass is still employed for condenser tubes with liquid velocities not exceeding 7 ft/sec., and for higher velocities associated with aeration 70:30 cupro-nickel tubes, with iron content of 0·4-1·0 per cent and manganese 0·5-1·5 per cent are widely adopted, particularly in warships and high class passenger liners, or otherwise the cheaper aluminium brass 76:22:2 inhibited with arsenic. Increasing attention is being given to the use of alloys of lower nickel content, e.g., 5 per cent nickel and 1·05-1·35 per cent iron. A cupro-nickel alloy, preferred in the U.S.A., contains 10 per cent nickel and 2 per cent iron.

Duplex tubing with different alloys for bore and external surfaces has been used, and in the U.S. combinations of various brasses, aluminium bronzes or cupro-nickel supplied with aluminium, Monel, nickel or steel external metals have been employed in chemical and refrigeration plant.

Shafting

The low corrosion-fatigue resistance of ordinary steel shafting has led to a wide adoption in the smaller sizes of copper- and nickel-base alloys which have excellent corrosion-fatigue characteristics in sea water. Manganese-, aluminium- and phosphor-bronzes, Monel metal and K Monel metal have all been used for shafting, including screwshafts of limited size, in the case of Monel metal up to 7½ in. diameter.

Propellers

These are subject to corrosion and erosion, and the employment of non-ferrous metals has been largely instrumental in preventing or considerably reducing these forms of attack together with improved propeller design. Alloys most resistant to erosion where cavitation is likely to be severe are austenitic stainless steels, aluminium bronzes with or without nickel addition, silicon Monel, Monel metal, high tensile bronze and Turbadium bronze, the latter being used extensively, e.g., the *Queen Mary* propellers weighing 32 tons each. In other cases, good service has been given with the normal manganese bronzes, silicon bronzes, phosphor bronzes, gunmetals and aluminium alloys. Propellers in large single screw oil tankers weighing 25-35 tons, and even greater, have been made of copper-aluminium alloys with nickel and iron additions, resembling that specified in B.S.1400 A.B.2, and copper alloy with high aluminium and manganese content. These copper-manganese-aluminium alloys have also been used for castings where high strength or a high resistance to corrosion is required.

Pump Impellers

These are usually made of gunmetal and manganese bronze and under severe conditions of stress and erosion, aluminium bronze, Monel metal or stainless steel are employed.

Fig. 4—Large Novoston propeller weighing 30 tons finished. (Courtesy J. Stone & Co. (Charlton) Ltd.)

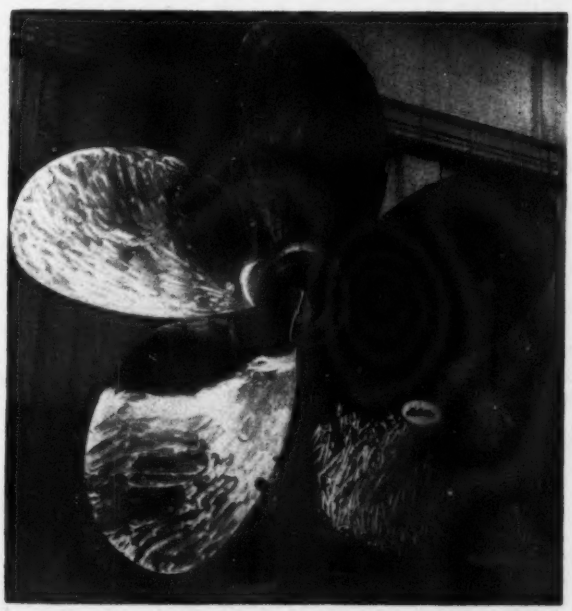


Fig. 5—Welded aluminium superstructure and other fittings on board S.S. "Sunrip." Weight saved by using aluminium was approximately 185 tons. (Courtesy Davie Ship Building Ltd. Sun Steamships Co.)

There are a large number of non-ferrous metal castings in the cast condition having weights less than 10 cwt. used for valve bodies and components, pump parts, bushes, brasses and similar items in all types of marine machinery, together with large pump casings, impellers and turbine nozzle castings weighing between ½ and 5 tons. Bronze castings with addition of lead are preferred for low pressure valve bodies and parts, sea connections and shaft liners requiring pressure-tightness, the aluminium bronzes being used for higher strength machinery parts.

On board ships all cables are subject to vibration and, ordinary lead covering proving very sensitive to fatigue conditions, research largely carried out by the B.N.F.M.R.A. produced improved sheathing using pure lead alloyed with small additions of tin, antimony and cadmium.

Hull Structures

Aluminium alloys are now the most important non-ferrous metals employed in certain types of ships, and their application is increasing with design and experience in spite of the cost being 8 to 9 times that of steel. The saving in weight is most marked in large passenger vessels having masts, superstructures, funnels, davits, hatch covers, lifeboats, sidelights, window and accommodation fittings in light alloys. In the case of the S.S. *United States* some 1,400 tons was used for the superstructure and 600 tons in minor bulkheads, furniture and fittings, giving a weight saving of 15-20 per cent of the original displacement. This is an outstanding example, the tonnage used in other merchant ships being of the order of 50 to 400 tons. The *Bergensfjord* (10,700 tons gross, built 1956) has 410 tons in superstructure above the weather deck, including main mast, funnel and guard rails, while for the cargo liners *Canberra* (45,000 tons gross) and *Oriana* (40,000 tons gross), and also the U.S.S. *Ranger*, the estimated weight is about 1,000 tons in the structure.

For oil tankers and dry cargo vessels, where the saving in top weight is not so important, the use of aluminium alloys is generally confined to the wheelhouses and similar deck houses.

Aluminium alloys in lifeboat construction have been a common practice for the past 25 years, particularly for passenger vessels and oil tankers. With diminution in size of naval vessels and the large increase in number of instruments, gadgets, etc., the greater use of light alloys becomes a necessity.

Undoubtedly, progress made in the use of these light alloys has been helped considerably through improved welding technique, and in consequence the sizes of small craft

entirely constructed of light alloys will steadily increase. For plate manufacture aluminium 3·5-5·5 magnesium alloy is usually employed, particularly for welded structures; an alloy with 5 per cent magnesium being used for rivets as well as 1 per cent magnesium-1 per cent silicon alloy.

Aluminium brass tubes are used for oil heating in the cargo tanks of oil tankers owing to satisfactorily withstanding the corrosive action of crude oil compared with mild steel and cast iron grids.

High-purity magnesium anodes are being used in the cathodic protection of seagoing vessels, vessels liable to be laid up in reserve and also to combat corrosion in oil tankers which carry alternately oil cargo and sea water in the same tanks. For hull protection zinc alloys are also replacing pure zinc where previously used.

The use of properly prepared hot dipped aluminium and sprayed metal coatings has helped considerably in minimizing corrosion and preventing excessive wear, in the latter case metal sprays used being stainless steel, nickel, high carbon steel and pure molybdenum.

Future Prospects

It is essential to appreciate the fact that reliability of operation of a ship is one of the most important considerations of the shipowner, since to earn money a ship must be at sea and able to undertake voyages in any part of the world as trade demands. It follows that progress in the marine field depends largely upon the satisfactory service of materials and machinery, and under modern conditions this is often based on their service in land installations. New materials generally mean increased first cost and doubt of behaviour under continuous operation with liability of higher maintenance costs, together with difficulty of replacement in ports far distant from the home base. Hence the need for care in the selection of new materials and a decision to sacrifice a degree of economy for reliability.

Accordingly, future utilization of new non-ferrous metals and alloys will, in the main, depend largely on weight saving and resistance to erosion and corrosion in marine environments, other matters, such as strength at high temperatures, being dependent upon service experienced on land. This does not mean that there is not ample scope for a further extension of existing materials often limited by cost. The shipowner, while naturally conservative, is not only on the lookout for new materials and improved methods of fabrication but also new types of machinery. Higher temperatures for steam turbines and more general adoption of gas turbines, all that is entailed in the adoption of nuclear energy for main propelling purposes and materials that will reduce costs of maintenance are all obvious possibilities.

In hull structures, light alloys, while now past the development stage, are dependent on reduction in cost and increased corrosion resistance. In salt water pipe systems where galvanized steel is still generally used the tendency is towards copper-nickel-iron and aluminium-brass alloys due to greater corrosion and erosion resistance qualities with competition increasing from plastics pipes, though the latter suffer from lack of heat- and fire-resisting qualities as well as cost.

At present a temperature of 1,050°F. appears to be the maximum for marine steam turbines and suitable materials are available, but with higher temperatures opportunities for the use of alloys such as Nimonic 90 for H.P. turbine blading and nozzles will be required. Titanium and its alloys which possess good mechanical properties and corrosion resistance have possibilities for L.P. turbine blading, but its high cost and difficulties in fabrication, e.g., brazing, makes it unattractive at the present time.

From an economical point of view the marine gas turbine needs to work at much higher temperatures, and here there should be greater scope for non-ferrous materials. Marine nuclear reactors are bound to follow land practice and experience which offer great scope for the less common metals such as zirconium, beryllium, niobium, vanadium, as well as molybdenum and tungsten. The power generating machinery will follow usual marine turbine practice.

Bearing metals will always offer scope for improvement to meet the more arduous and widely varied conditions of service with extended use of thin shelled bearings and lead and indium coatings.

There is still room for improved alloys for propellers to meet all conditions of future service.

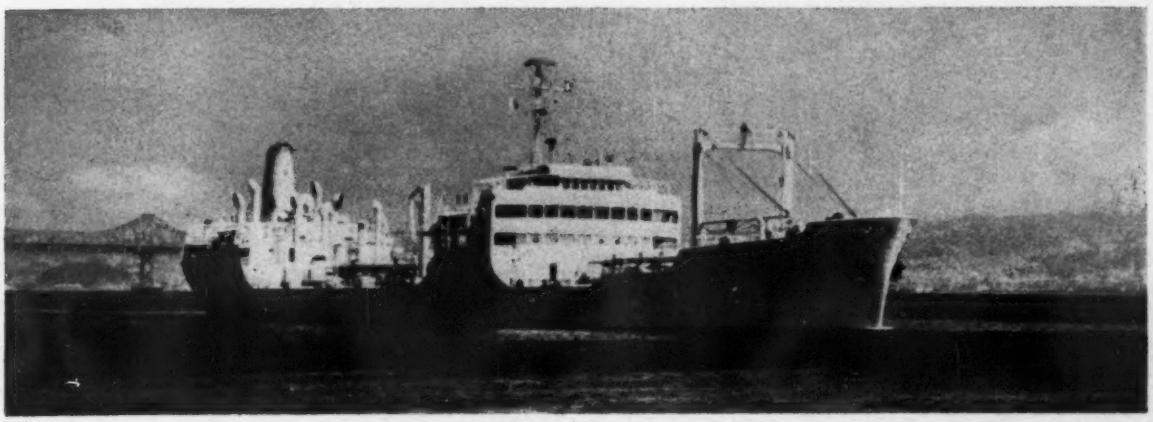
In the electrical field, the magnetic characteristics of non-ferrous metals alloyed with iron, have potential possibilities and together with high resistance alloys, offer scope for further research and development.

If the transportation of liquid methane in bulk proves successful, there may be an increasing demand for aluminium-3 per cent magnesium alloy plate and section. This material has adequate toughness for operation at −259°F., the boiling point of liquid methane.

In conclusion, it is only proper to say that many of the new non-ferrous metals have limitations of resources and production which at present retard their uses, but there is no doubt that research and development can rapidly alter this position and the most efficient and economical selection of metals be made to the benefit of all users.

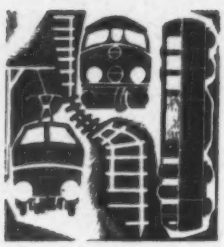
The writer is indebted to Sir James McNeil, F.R.S., of Messrs. John Brown & Co., Ltd., Clydebank, Mr. C. C. Pounder of Messrs. Harland and Wolff, Ltd., Belfast, and some of his former colleagues at Lloyd's Register of Shipping for their ready assistance in the preparation of this article.

Fig. 6—Wine ship "Angelo Petri" carries its cargo in stainless steel tanks at a speed of 15 *knots.* (*Courtesy The Mond Nickel Co. Ltd.*)



1909 - 1959

NON-FERROUS METALS IN THE



Railway Industry

by T. HENRY TURNER
M.I.Mech.E., M.I.Loco.E., F.I.M.

Former Superintendent of the Metallurgy Division, British Railways Research Department

IN this review of the past fifty years we have to consider three distinct periods of changing railway practices: (1) before 1923; (2) the four Grouped Railways, 1923 to 1947; and (3) British Railways, 1948 to date.

Few of the present generation will have seen the famous trains of the first decade of this century, but the writer has in his possession a tattered old album in which there are a hundred picture postcards, such as had a ready sale to boys in those days. Many of these are in bright colours and illustrate such famous trains as *The Scotch Express* of the North Eastern Railway, *The Flying Dutchman* of the Great Western Railway, and the "Fishguard Boat Express to Ireland", also of the G.W.R.

During the second period under consideration the writer was himself a railwayman, having been appointed "Chief Chemist and Metallurgist" of the L.N.E.R. early in 1930, and one of the first things which he was instructed to undertake was the selection of the non-ferrous metals and alloys which should be standardized by the Chief Mechanical Engineer for use in all the locomotive, carriage and wagon workshops which the management had inherited from the six great railways which had gone to form the L.N.E.R.

Soon after the commencement of the third period the nationalization of all the group railways required similar work and the writer was appointed chairman of "The Railway Executive Mechanical and Electrical Engineering Policy Committee on Non-Ferrous Metals". Complicated as this work was it had been made of comprehensible dimensions by the work which had been carried out on each of the group railways twenty years before.

Metals Used

In all our main-line steam locomotives the frame, springs, axles, wheels and tyres were made from the appropriate grades of steel; the cylinders were of cast iron, and the boiler was made from steel.

There was, however, a considerable weight of non-ferrous metals in the arsenical copper firebox plates and stays, and in the earlier days there were also many copper tubes in the boilers. The boiler fittings were generally made from bronze castings and bronze was used for many of the engine motion bushes and for the bulk of the wheel bearings; the latter being lined with one or another of many grades of white-metals, made from alloys of tin-lead-antimony-copper.

The weights of metals used in a locomotive varied according to its class and year of construction. Gradually the size of the better known passenger locomotives grew until, towards the time when the writer's 20 years of service in charge of the L.N.E.R. laboratories was ended by the nationalization of all the railways, their main-line express locomotives each contained nearly 5½ tons weight of non-ferrous metals and alloys.

At the time of the nationalization of the railways the quantities of non-ferrous metals which they were using were probably as shown in Table I.

Fig. 1—Main-line diesel locomotive (2,300 h.p.) for hauling express passenger and parcel services. (Courtesy British Railways)

Table I—Consumption of Non-Ferrous Metals

Metal	Wrought (plates, tubes, wire, sheet, bars, etc.) Tons	Cast Tons
Bronzes	10	10,000
Copper (not electrical)	5,000	—
Whitemetals	—	3,775
Lead	750	1,000 (for batteries)
Brasses	600	400
Zinc	140	—
Solders, etc.	—	100
Packing Metals	—	70
Monel metal	60	—

More recent figures (supplied by the B.T.C. Chief Supplies Officer) show the consumption of metals by British Railways to be as follow:

Lead	1948/9	2,050	..	1953/4	2,420
Antimony ..	1948/9	110	..	1953/4	87
Tin	1951/2	634	..	1955	682
Copper plate ..	1950/1	3,437	..	1958	2,500
Monel metal ..	1948	145	..	1958	177
Steel	1948	582,800	..	1958	797,258

Fifty years ago, each Chief Mechanical Engineer drew up his own list of materials of construction, on the basis of his own particular railway's experience with the interplay of design qualities and the nature and reliability of such materials of construction as were available at reasonable prices.

It must have been at the beginning of the fifty years period which we now have under review that British Standards, as we now know them, began to be prepared and promulgated by the British Engineering Standards Association (B.E.S.A.). That body was the forerunner of the now flourishing British Standards Institution (B.S.I.), whose specifications are now very widely used by the engineers of British Railways; indeed it is the accepted policy of the British Transport Commission to refer to these specifications wherever possible for all the materials used in the construction and in the maintenance of railway track and rolling stock.

Fifty years ago, the railways of this country hauled, on their own standard gauge lines, a motley of privately owned wagons of many shapes and sizes. Generally, their main frame, sides and ends were constructed from wood. If they "ran a hot box", i.e. experienced an axle bearing failure, when running on the track of the main lines a catastrophe might result, of far more serious importance than the original bearing failure.

Consequently, through the famous Railway Clearing House, agreements were hammered out in regard to the bronze for the bearings and for the whitemetal alloy with which it should be lined. These R.C.H. Standards applied to all privately owned wagons, which were generally manufactured by independently owned non-railway firms of wagon builders.

Since nationalization there has been in existence a committee which has worked through all the many specifications of the former group railways for ferrous materials. They have chosen the appropriate British Standards and, where necessary, produced a new British Railways specification to pinpoint the alternatives or special details required.

No such work has been required for the non-ferrous metals and alloys.

When British Standards, which are of interest to the railways, come up for revision, the B.S.I. normally invites a representative of the B.T.C. The latest issues of the British Standards listed in Table II were in use at the formation of British Railways.

Metallurgical Control

Specifications are only of real value if they are taken seriously and that entails in the case of metals that there shall be, both on behalf of the producer and of the user, a properly controlled system of inspection.

When the present writer took charge of the four laboratories of the L.N.E.R. in 1930, they included in their staffs no assistant who had been trained as a metallurgist. During the next ten years the small "Metals Section" which he built up at Doncaster learned to know, and to be able to show at short notice, the chemical compositions, microstructures, and physical properties of every metal and alloy used by the L.N.E.R.

Metallurgists were employed on the L.M.S.R. in three or four of their main works and they also built up, under Dr.

Fig. 2—"The East Anglian" express hauled by Type 4 2,000 h.p. diesel electric locomotive. (Courtesy British Railways)

H. O'Neill, a small team of metallurgists in their Scientific Research Department at Derby.

After nationalization, the employment of works metallurgists was extended until there were small teams of "Regional Works Metallurgists" available to the Locomotive, Carriage and Wagon, and Electrical Engineers in each of the six Regions; in each of these teams there has been included an expert on welding.

The metallurgical work required for the Civil Engineers in connection with their structures, bridges and track and also the work required for the Signal Engineers has been handled by the Metallurgy Division of the British Railways Research Department. Its headquarters are located in Derby, but it has all-country responsibilities.

Inspection in all the six Regions has been co-ordinated and linked together under a chief who is also located at Derby but responsible to the Chief Mechanical Engineer of the British Railways Central Staff.

Stationary X-ray plants are available in some of the works and two railway coaches fitted as mobile X-ray Laboratories are employed, mainly for the training of welders or for on-site investigation of bridges.

Pure lead has also found a use as the fusible part of the safety fitting screwed into the top of the fireboxes. Known as a fusible plug, this device has contributed much to the maintenance of the truly amazing record of freedom from boiler explosions on British Railways.

Many non-ferrous metals are used in the railway's electroplating shops, which employ anodes of brass, cadmium, copper, lead (hard antimonial for use in chromium plating), several varieties of nickel, silver and zinc.

Metal-spraying did not exist in Great Britain fifty years ago, but it had been introduced as a commercial possibility when the present writer studied it and wrote about it in 1925. From 1935 onwards he was able to test metal-spraying on steel for various railway purposes. Many promising uses of the process were nullified by the need for cleaning down to bare metal during the essential periodical inspections. Unexpectedly, one of the most successful uses for the process turned out to be for building up the backs of worn press fit bushes.

Most of the railway works now possess metal-spraying pistols which they use in repair and maintenance operations. Sprayed metal coatings of zinc or aluminium are now considered in competition with hot galvanizing with zinc for the protection of iron and steel against atmospheric corrosion (see B.S. 2565:1955) and such uses of non-ferrous metals as coatings have become of increasing importance because of the great tonnage of steel which will have to be exposed to atmospheric corrosion in holding up the conductor wires for the coming electrification of the main line railways.

Table II—Some Specifications for Non-Ferrous Materials Used by British Railways

B.S. No.	Title	B.S. No.	Title
24	Copper and Brass (Railway Rolling Stock)	441	Cored Solder, Resin filled
206	Silver Solder	602	Lead Pipes
218	Brass Bars and Section (Suitable for Forging) and Drop Forgings	603	Lead Pipes (B.N.F. Ternary Alloy No. 2)
219	Soft Solders	643	Capping Metal for Wire Ropes
220	Zinc (fine)	849	Plain Sheet Zinc Roofing
249	Brass Bars (High speed screwing and turning)	885/6	Seamless Brass Tubes
263	Brazing Solder	889	Cold Rolled Copper Sheets and Strip
264	Hot Rolled Yellow Metal Plates, Sheet and Strip	1004	Zinc Alloys for Die Castings
265	Cold Rolled Brass Sheets, Strip and Foil (Copper 61·5)	1085	Lead Pipes, Silver-Copper-Lead-Alloy
267	Cold Rolled Brass Sheets, Strip and Foil (Copper 64)	1172/4	Deoxidized and Arsenical Coppers
269	Phosphor Bronze Bars and Rods	1178	Milled Lead Sheet and Strip
375	Refined Nickel	1400	Copper Alloy Ingots and Castings
384	Hard Drawn Phosphor Bronze Wire	1470/7	Aluminium Sections
407	Phosphor Bronze Sheets, Strip and Foil	1490	Aluminium and Aluminium Alloy Ingots and Castings
		1529	Nickel and Nickel Alloy Bars, Rods and Sections

Applications of Non-Ferrous Metals

Copper and its alloys have been widely used. In the form of arsenical tough pitch copper it has been used almost universally and continuously for the locomotive firebox side and top plates, which are in direct contact with the heat of the fire. Scrapped firebox copper was used in the locomotive works brass foundries for making such things as axlebox bearings, bushes for engine motion and side rods, boiler mountings, injectors and so on.

Year by year, a growing tonnage of copper was used for electrical conductor wires, and this usage of copper by the railways is now being increased deliberately at an accelerated rate.

Whitemetals were used for lining most plain bearings of the British Railways; although leaded bronzes were employed for the same purpose in America. Tin-base whitemetal alloys were the most popular, but lead-based alloys have been used in increasing quantities in wagon bearings during recent years because of the wartime uncertainties as regards the availability of tin, and also on account of their relative cheapness in first cost.

Lead has been used in increasing quantities, especially in the form of antimonial lead for electricity storage batteries, because this fifty years has seen the replacement of the older oil-gas incandescent mantle carriage lighting in all passenger coaches, by the cleaner and much more convenient electric lighting. Hence all passenger coaches now carry one or more large lead-acid type storage batteries slung below their steel frames.

Reclamation of Scrap

It was estimated some years ago that 27,000 tons of non-ferrous metal scrap, worth about £3,000,000, were produced each year by the machining operations and breaking up and repair programmes of the locomotive carriage and wagon works of British Railways.

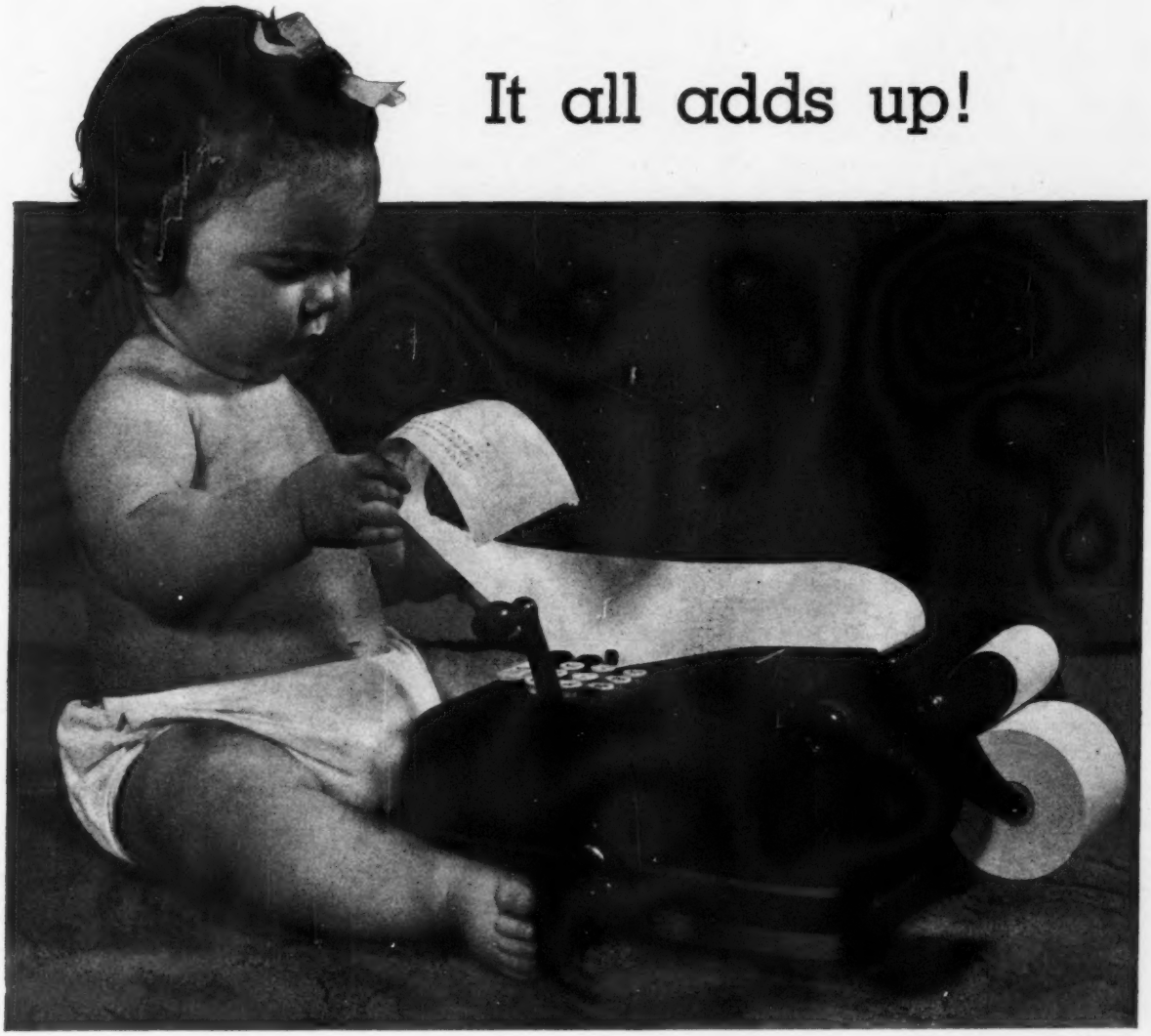
As much as possible of this metal was reclaimed for re-use, so long as that could be done without complicated refining processes.

The L.M.S.R. carried this work of scrap collection and segregation furthest with their Central Reclamation Depot at Derby, but all the railways had systematic schemes in operation.

In this way, whitemetals, packing metals, brass and bronze turnings and castings, zinc sheet, lead sheet and pipe, copper wire and cable, whitemetal dross, shop sweepings and so on were all dealt with.

Thousands of tons of renovated whitemetal ingots and of brass and bronze ingots thus returned to the railway foundries each year.

At the time of nationalization there appeared to be an



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E

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With aluminium castings the knocking-out of cores can become a foundry nuisance and problem. To the foundry which made this gravity die cast aluminium gas burner, the problem was threefold.

1. The core had to be strong enough to withstand gravity die cast conditions.

2. The core had to liberate the minimum amount of core gases, otherwise the casting would not withstand the final gas pressure tests.

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Fig. 3—"The Elizabethan" hauled by Class A4 locomotive "Silver Fox". (Courtesy British Railways)

excellent opportunity to set up Works Metal Scrap Depots and Regional Metals Reclamation Depots of modern design.

However, the rhythm of non-ferrous metal purchase, use, reclamation and re-use has been seriously upset by the decision to abolish the steam engine.

With diesel engines made in many non-railway factories, the scrap arising in the future will be more varied. Yet the maintenance of diesel and electric engines will be done in railway works. Hence railway non-ferrous metal scrap will in future be more varied.

Compositions of Alloys Used

Rule of thumb and the inherited practical experience helped the foremen of the many railway brass foundries to produce satisfactory castings, not always, of course, but each foundry had its own formulae.

When the writer was told to make recommendations for the bronzes, brasses and whitemetals to be used by the L.N.E.R. he was informed of many attempts which had been made to assess the service life to be attained by this or that alloy. All too often these tests on the track had proved nothing. Eventually, in 1933, he put forward seven compositions for cast bronzes or brasses, and two for whitemetals, and these were promulgated by Sir Nigel Gresley for use in all the L.N.E.R. locomotive, carriage and wagon works.

About the same time, the other three group railways produced their own standards, but practice varied somewhat from railway to railway. Thus the G.W.R. had only one bearing metal for locomotives, carriages and wagons; the L.N.E.R. had two, and the L.M.S.R. had four.

During the next eight years there were few changes and the railway non-ferrous practice gradually benefited from the measures of standardization achieved.

Shortage of tin during the 1941-6 period brought about wartime modifications and in order to reduce the quantity of tin used, the well-known 85-5-5-5 alloy came to be employed in the place of alloys which had contained in pre-war practice 13 per cent, 10 per cent or 7 per cent of tin. Experience seems to have shown that these higher tin contents were justified for railway work. From that it came about that the L.N.E.R. reverted to its pre-war compositions of bronzes before 1948.

Fig. 4—"The Merchant Venturer" train at Wootton Bassett running on flat bottomed track. (Courtesy British Railways)

The other companies were less quick to act before the Transport Act of 1947 introduced the Railway Executive to manage, operate and maintain the whole of the main-line railways, on behalf of the British Transport Commission which the Government had just created.

There were at that time seventeen brass foundries, which through the four group railways the Railway Executive had inherited from the many former private railways. Between them they were casting no less than 37 different compositions of copper-based alloys. Outstanding from these were the 85-5-5-5 and the 13·25 per cent tin phosphor bronze. The L.N.E.R. used the latter for the solid bronze axleboxes of many of its most famous locomotives, one of which held the world record for speed by a steam locomotive.

The more complex high tensile brasses and aluminium bronzes were not used because they gave trouble in the foundries and in service.

These were some of the facts to be considered when the writer was made chairman of the Railway Executive committee which was set up to report on what non-ferrous metals were being used on rolling stock, what reclamation of scrap was being done, and to recommend the alloys and practices which should be used in the future.

There is a fundamental difference in practice which must be borne in mind in this connection. Whereas most engineering component makers have a one-way traffic, they make their product and send it away, the railways always have much maintenance work in which their own components return to them as scrap for re-use or sale as may be most economical. In this way, much scrap of known constant composition has in the past been available to the railway foundries. With simple standard mixtures such remelting practices can be exceptionally economical.

For whitemetals, the simplest policy was that of the G.W.R. and the writer would have liked to adopt their single alloy, but it was decided otherwise, and the four bearing metals which have been used by British Railways during recent years are as listed in Table III.

For bronzes and brasses cast in their own foundries British Railways have during recent years endeavoured to keep to the five alloys listed in Table IV.

As a general indication of what these five alloys are used for it may be said that No. 1 is for slide valves, unlined bushes and machinery details; No. 2 is for the slide valves of unsuperheated engines; No. 3 is for steam and boiler mountings, axleboxes, lined bushes and brasses, carriage and wagon bearings and so on; No. 4 is used for name and number plates, carriage fittings and such purposes; and No. 5, as its name implies, is used for fittings which are to be brazed on to copper or steel pipe.

For wrought non-ferrous alloys reference is made to B.S. specifications such as those listed in Table II. During this period hot stampings or pressings of B.S. 218 have replaced the traditional railway bronze castings; for example for the bodies of fusible plugs and for washout plugs.

Table III—White Metal Bearing Alloys Used by British Railways

Chemical Composition	1 High-tin Lead-free	2 High-tin Low-lead	3 Lead-tin base	4 Lead base
	%	%	%	%
Tin	84-86	80-85	58-60	11-13
Antimony	9-11	9-11	9-11	12-14
Lead	0·2 max.	0-5	27-29	73·5-75·5
Copper	4-6	4-6	2-4	0-1
Total impurities max.	0·30	0·30	0·35	0·40

Table IV—Bronzes and Brasses Used by British Railways

Chemical Composition	1 Phosphor Bronze	2 Leaded Bronze	3 Leaded Gunmetal	4 Yellow Brass	5 Brazing Metal
	%	%	%	%	%
Copper	87·5	67·5	86	66	90
Tin	12	5	7	—	—
Lead	—	26	2	2	—
Zinc	—	—	5	32	10
Others	P 0·15 min.	Ni 1·5	—	—	—

The Future

This review of the changes in practices which have occurred during the last fifty years naturally invites some forecasting of the changes which are to come. Railway uses of these metals were centred about the steam locomotive, which was made and maintained in the railway's own workshops. The Chief Supplies Officer of the B.T.C. has noted that copper plate consumption on British Railways dropped from 3,437 tons in 1950/1 to 2,500 tons in 1958. Even without the introduction of the internal combustion engine and of the now inevitable electrification, there would have been notable changes.

Steel fireboxes are lighter in weight and they become essential for the higher steam pressures to which design must tend, and with properly controlled boiler water treatment they last longer than do the copper boxes as now used, moreover the steel boxes are cheaper. The use of copper for locomotive firebox plates and stays was therefore on the way out in several countries even before the decision to build no more steam locomotives for the main-lines was published. In a number of years' time there will be no more call for the successful, and recently increased to 177 tons per annum, use of Monel metal for locomotive boiler stays.

Plain bearings of non-ferrous metals reigned supreme fifty

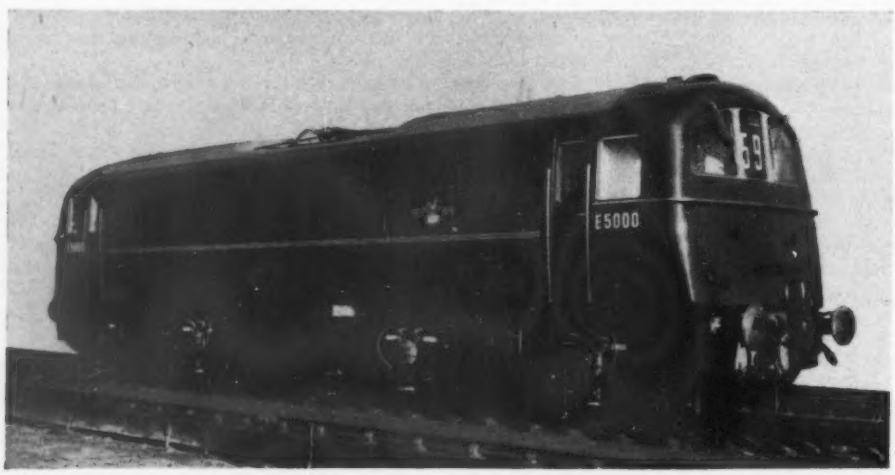


Fig. 5—2,500 h.p. Bo-Bo electric locomotive for use on the third rail D.C. electrification of the Kent Coast lines. (Courtesy British Railways)

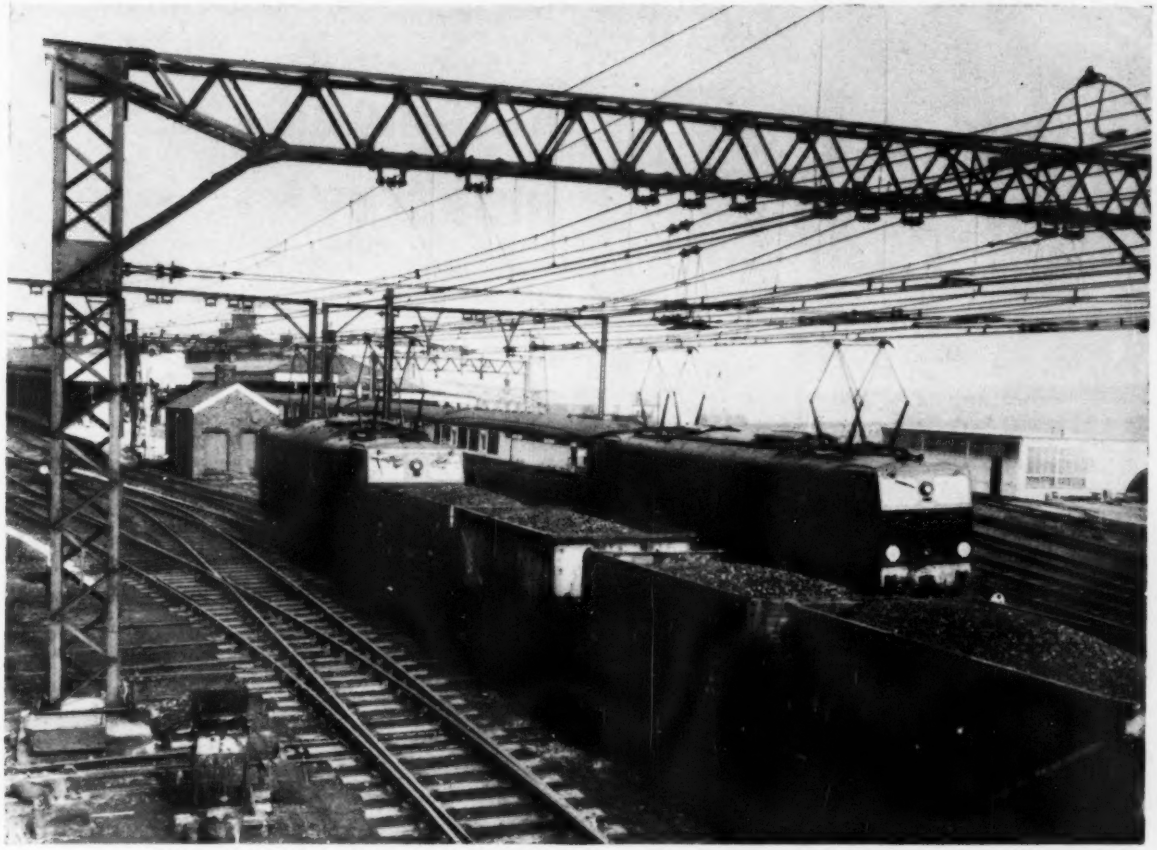


Fig. 6—Electrification on the Manchester-Sheffield-Wath lines 1,500 *volt D.C. Overhead with rail return*

years ago in railway practice. Now one may see various kinds of roller bearings, all made from steels, in steam, diesel, and electric locomotives, in electric passenger stock and in modern high speed freight vehicles. Some white-metalled bronze bearings and exotic sintered materials may find a place in future railway practice but more and more roller bearings will be employed in the material ordered for the modernization of the railways.

All the coming electrification will require copper; in vehicle motors, pantographs, switchgear, conductor wires and so on. The overhead electrification of the main-lines in Great Britain and in many other countries will require a very great tonnage of copper, and much more copper will be required quite soon as electrification spreads to all signalling and other ancillary services. Overhead equipment for the 25 kV, 50 cycles electrification of the two main line routes from London to the North will contain well over 10,000 tons of copper and cadmium-copper conductors.

Fifty years ago there was no welding of copper for locomotive firebox plates and stays; the plates were all riveted and the stays screwed and riveted.

Many troubles had been encountered whenever attempts were made to weld arsenical tough pitch copper plates in fireboxes. Then led by the G.W.R. at Swindon in the 1930's a change was made to the use of deoxidized arsenical copper, which gave less trouble in welding. Hence, despite the relatively great heat and electrical conductivity of copper, which complicates the process, welding of copper will be practised, not, however, to the exclusion of the long established and very convenient riveting process which is still widely used in normal maintenance.

Experiments with aluminium alloys in railway work have been disappointingly slow for the producers of these alloys, but the use of unpainted aluminium bodywork for the latest trains on the London Underground Railways of the L.T.E. has brought aluminium into the railway field in a very notable manner. Aluminium has also been used in light-weight diesel multiple unit stock for passengers, British Railways Carriage and Wagon Works, Derby, having recently produced their 414th car in aluminium alloy since 1954. Its further employment will hinge on comparative costs now that its availability and engineering properties are better appreciated.

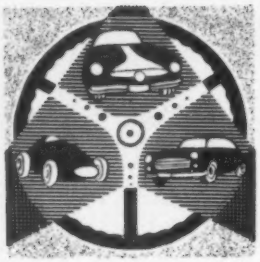
Aluminium and zinc will be more widely used in the form of corrosion resistant coatings for the protection of steel and for reducing the costs of repainting. As routine maintenance costs attract more attention the preliminary galvanizing, or metal spraying of railway components, will use up more of these two metals.

Non-ferrous metals enter railway service in a great variety of proprietary articles, so it is not possible to give accurate figures for the tonnages in use.

But in railway engineering it is the rule that steel requires to be associated with non-ferrous condensers, radiators, electrical conductors, and so on. Hence, when the British Railways increased their consumption of steel from 582,800 tons in 1948 to 797,258 tons in 1958, they correspondingly increased their consumption of all the non-ferrous metals.

1909 - 1959

NON-FERROUS METALS IN THE



Automobile Industry

by R. J. BROWN,
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FIFTY years ago, the motor industry was still in its infancy, but showing distinct signs of very healthy development. In the year 1909, a total of 11,000 motor cars and commercial vehicles was produced in Great Britain and in three years this figure was more than doubled at 23,000 and trebled by the following year. Although the First World War undoubtedly halted the phenomenal increase in output, it provided a sound reason for the general acceptance of the motor vehicle for rapid transportation. The first decade after the war saw a steady increase in output, followed by a rapid increase in the first part of the second decade due to the general adoption of mechanization by the motor industry. This increase was slowed down in the latter part of the decade as the nation geared itself to war production, and output subsequently fell to the level necessitated solely by the demands of the armed forces for the period covered by the Second World War. Immediately hostilities ceased, the motor industry made an amazing recovery and from 1946 output has increased almost by arithmetical progression, as can be seen by reference to Fig. 1, reaching the amazing total of 1,364,000 cars and commercial vehicles for 1958, this total excluding a further 200,000 agricultural tractors.

It is of interest to trace the relationship between the consumption of the major non-ferrous metals and the output of motor vehicles in Great Britain during most of the period under review, and of their price in relation to average wages paid in the engineering industries. Reference to Fig. 1 shows that during the period of the Second World War there was a phenomenal increase in consumption of metals with a fall in car output. The resumption of normal conditions caused the curve to assume a similarity to pre-war form, but with a much more rapid increase in car production than in metal consumption. The somewhat wild fluctuations in the price of metal during the period of the first world war and also more recently during the period of the Cold War are shown in Fig. 2, but it is particularly interesting to note that the increase in car prices has been proportionately lower than either the increase in wages of recent years or the increase in certain metal prices, an indication that the best use is being made both of labour and of materials by the motor industry of this country.

During this period of development and expansion of the motor industry, the whole conception of design and styling and methods of production have undergone revolutionary changes, as have consequently both the type of materials employed and their application. The industry commenced with the building, in the latter part of the last century and the first decade of the present century, the horseless carriage, in which the body shape and style of the horse-drawn conveyance were retained to a considerable extent. From this type of vehicle the landaulette developed, with the engine where the horse might have been expected, a good example of such a vehicle being the 1908 Austin landaulette,

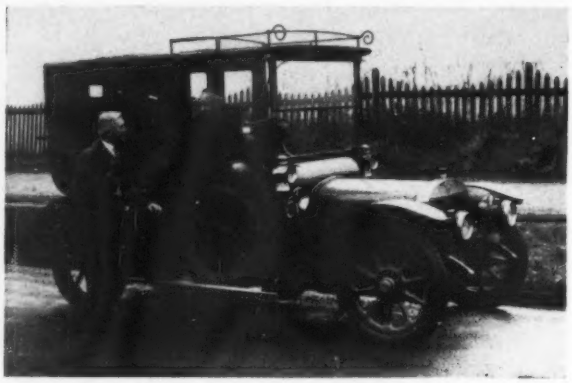


Fig. 3—1908 40 *h.p. Austin Landaulette*

shown in Fig 3, in which the body construction was of materials normally used for horse-drawn vehicles, largely timber framing with steel reinforcements, upholstered with leather over hair stuffing and embellished with brass fittings and lamps. The power units and transmissions of that period were of heavy construction, although the engine had become a multi-cylinder unit, but of large bore with a massive gear train to transmit the power developed, using a leather surface clutch and a transmission brake coupled to the propshaft; in the earliest vehicles, rim brakes, as used on horse-drawn carriages, had been retained.

Examples of the evolution of the motor car during the past 50 years are shown in Figs. 4 to 7, and probably of particular interest are the baby cars shown in Figs. 6 and 7, both of which made their mark with the motoring public and were, or are being, produced in vast quantities, approximately 300,000 Austin 7 h.p. cars having been produced between the years 1922 and 1939, and over 750,000 Morris Minors, excluding vans, from 1948 to the present time.

Copper and Copper-Base Alloys

These materials comprised the bulk of the non-ferrous metals used in the early motor car, for such applications as inlet manifolds, water pipes, fuel and oil pipes, lamp brackets, door handles, hinges and windscreen and window frames. More important components, such as the rear drive gear, were also made of copper-base alloys as were the many bushings and bearings. The majority of these parts were manufactured from castings, and their total weight in relation to that of the vehicle was quite high. Fifty years ago the labour content of the finished vehicle was extremely high and therefore the material content and cost of materials was somewhat less important than it became with the advent of mass or quantity production and the more recent adoption

of automation. The provision of electrical equipment ensured regular consumption of copper, electric lighting sets having been produced by Lucas as long ago as 1910, and complete equipment comprising generator, starter, battery and lighting in 1912.

The use of this class of material for automobile engineering purposes has now become restricted to those components and applications for which no alternative material is satisfactory; this is largely owing to its high relative cost, but it is keyed also to the progressively increasing knowledge of lower priced alternative materials and finishes. Whereas the early motor car was made decorative by the judicious use of copper and its alloys, the modern car makes little apparent use of these materials, although they do comprise some 40 lb. weight per motor car, of which some 20 lb. is to be found in the radiator, 10 lb. in electrical equipment, and 10-15 lb. in miscellaneous parts such as bushings and unions. The primary use of unalloyed copper is in the

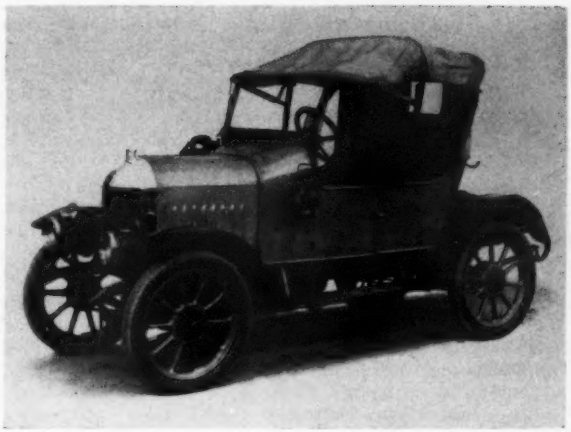
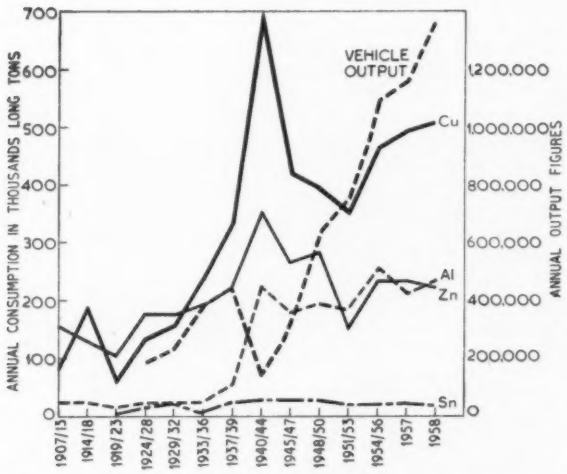


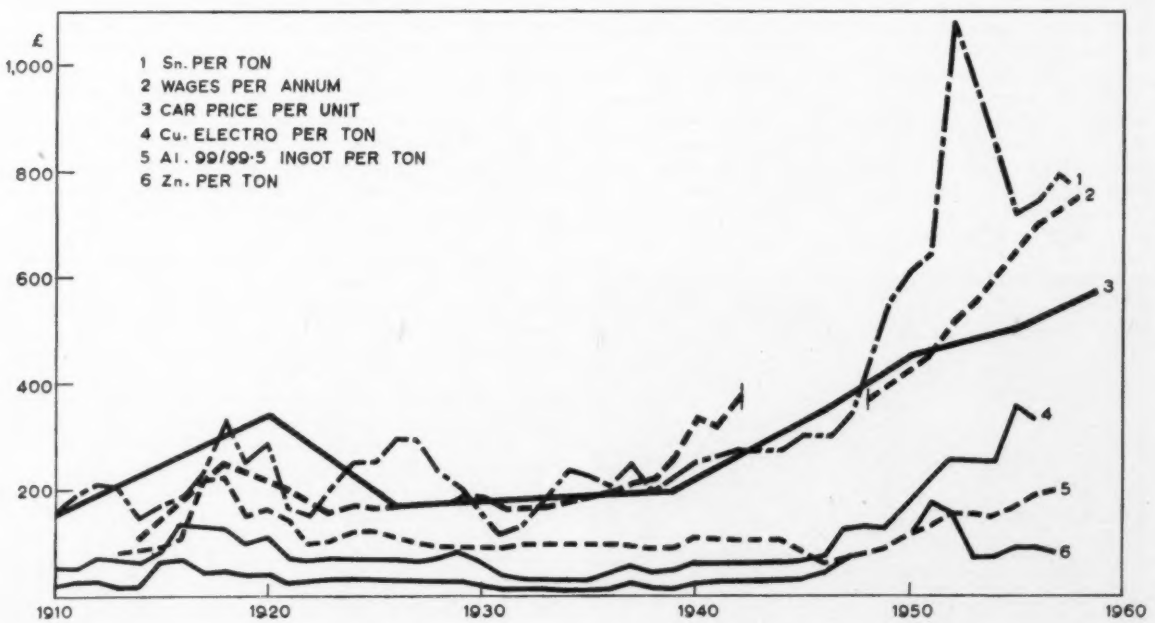
Fig. 4—1913 *Morris open tourer*

electrical system for wiring; whereas copper pipes were originally used for brake and fuel lines, this application has been replaced by the adoption of "Bundy" tubing, which, however, makes use of copper as the brazing medium for the continuously cold-formed pipe, as shown in Fig. 8.

Brass is used mainly for radiator construction, for thermostat bellows, and for pipe unions, and a certain amount is still used as the basis for bright plated trim, but owing to its relatively high cost it is being largely replaced with stainless iron or anodized aluminium. Aluminium bronze is used to a limited extent for engineering components, particularly in the gearbox for selector forks. A considerable tonnage of gunmetal and phosphor bronze was used in the cast form for bearings and bushings and for worm gears in the early days of the motor industry, the castings employed being relatively massive in form, but these have largely given way to cold formed bushes produced from phosphor bronze strip or to sintered powder



Above: Fig. 1—*Motor vehicle output in relation to consumption of non-ferrous metals. Records based on average per three-year periods*



Below: Fig. 2—*Motor vehicle prices in relation to wages and non-ferrous metal prices*

Fig. 5—1959 *Riley* 4/68 *saloon*

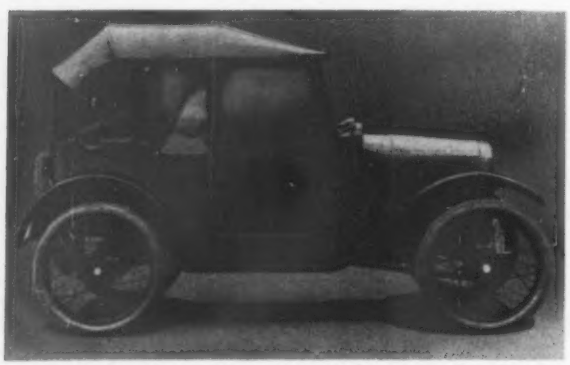
bushings, and the bulk of worm gears has been replaced by the spiral bevel and hypoid types of gearing for rear axles.

Copper-lead bearings have, to a considerable extent, replaced the tin-base Babbitts used so extensively during the past 50 years in the motor industry; they have the advantage of much higher fatigue strength, and modern methods of production have been developed which are not only economically advantageous but also enable a much better control to be exercised over the structure of the bearing metal. Copper-lead bearings are a necessity for high performance engines owing to the relatively low fatigue strength of tin-based Babbitt, and they perform quite satisfactorily when used in conjunction with steel journals of intermediate hardness, although early experience with this class of bearing had given rise to the belief that only journals having a very high surface hardness would operate successfully. Individually cast bearings may have a pronounced dendritic structure, but when carefully produced their structure is as shown in Fig. 9; continuously cast strip has a similar structure, lead segregation in both processes being prevented by the intentionally rapid cooling rate. A very high proportion of this type of bearing, however, is produced from steel having a sintered alloy coating, the sintering process of coating making possible the successful production of bearings having a high lead content, a typical structure being shown in Fig. 10.

Future developments of power units, possibly incorporating aluminium cylinder blocks, may necessitate the general use of high duty bronze valve set inserts and valve guides, such alloys being basically aluminium bronze with additions of nickel and iron; at the present time, they are used only for special and high performance engines.

Porous bronze bushes impregnated with oil were first adopted by the Austin and Morris companies in 1934, their use being limited to relatively light duty applications. Other powder metal products used include filter elements with closely controlled orifice size, roller bearing cages, door catches, etc. Also of interest are the porous bronze bushes impregnated with tetrafluoroethylene, the porous base providing adequate support for the relatively low strength P.T.F.E., and at the same time a reservoir for replacement of the surface layer should it be damaged in service.

Fig. 6—1922 *Austin* 7



Aluminium

An early example of the application of aluminium alloys in a mass-produced vehicle was the Austin 7, in which no less than 26 separate aluminium castings were employed and which also incorporated liberal use of aluminium panelling in the body structure.

Prior to World War I, high priced cars made use of light alloy castings for the crankcase, gear box casing, rear axle housing, water pump, steering box and steering wheel, and also for body panels. In the period following that war, certain high performance cars employed aluminium cylinder blocks, and aluminium pistons became accepted as standard equipment. However, it is only in the period following the Second World War that aluminium alloys have made any great headway, on a tonnage basis, raw material costs having held back the widespread adoption of this versatile metal. Popular cars in the middle price bracket, of which the Austin A55 and Morris Oxford are typical examples, contain up to 40 lb. weight of aluminium alloys in the form of crankcase, gearbox casing, rear axle casing, pistons, etc., whereas the overall average, including commercial vehicles in which a much greater proportionate weight of aluminium is used, is approximately 80 lb.

The general adoption of aluminium alloy pistons as a replacement for those of cast iron resulted from the fact that the advantages more than outweighed the increased cost. The advantages arise from reduced stresses on the bearings and crankshaft, better cooling of the piston crown with consequent reduction in carbonizing of the oil, and associated reduction of oil consumption. The early piston alloys were of the L8 (12 per cent copper type), subsequently replaced by Y alloy, which possessed higher hardness at working temperature, together with greater strength; this was later replaced, about 1934, by the Lo-Ex alloy, which has as its main attributes excellent hot strength and hot hardness, with the lowest coefficient of expansion for those types of aluminium alloy suitable for pistons, so that piston clearances could be reduced, thus overcoming troublesome piston slap, which occurred as the result of excessive clearance between the pistons and bores when the engine was cold. The closer fitting of pistons, however, gave rise to non-uniform expansion leading to local seizure, and this was partly overcome by attention to design and partly by surface treatment to reduce frictional effects, these latter being either anodizing to provide a highly absorptive oxide film coupled with high surface hardness, or tin plating by conversion from a sodium stannate bath to provide a soft low friction surface.

The early general purpose casting alloys used were of the L5 type (12½-14½ zinc), having a tensile strength of the order of 11 tons/in^2 when chill cast, but the bulk of general engineering castings used by the motor industry are now in LM4 or LM1, with a tensile strength of a similar order.

Apart from stressed applications, aluminium is now finding increasing use as a decorative trim material; its main feature is its inherent corrosion resistance, but to obtain the necessary scratch resistance it has to be anodized. Whereas interest on the Continent has tended to centre on the use of super purity material (99·99 per cent) alloyed with 1¼ per cent magnesium, economics have dictated the use of a lower purity base of at least 99·7 per cent, which, by careful production and processing, provides a finish at a competitive price comparable to that of chromium plate. The future will undoubtedly see the increasing adoption of

aluminium trim as supplies of suitable material become available, and as the motor car body designer learns to accommodate its somewhat lower strength, which necessitates additional care in handling, both during production and in assembly. As an alternative to a highly reflective trim, commercial aluminium of 99·5 per cent purity, with or without the addition of magnesium, can provide a bright satin finish, which has so far been little used.

Possibly the greatest interest at the present time centres on the future of aluminium alloys for motor vehicle engines, for the cylinder block itself. Such an application is far from new; as early as 1898 aluminium crankcases were used for the de Dion Bouton engine, aluminium pistons in 1913 in DFP cars, and 4 or 6 cylinder engines for "all-aluminium cars" of an experimental type. In the immediate postwar period, aluminium cylinder blocks have only been used for high priced high performance cars with, generally speaking, wet ferrous liners, and aluminium heads with cast iron cylinder blocks for sports cars. It is only during the last two or three years that serious interest has developed in the possible application of mass produced aluminium engines, largely as the result of the constant demand in the U.S.A. for engines producing even higher power output having

Fig. 7—1949 *Morris Minor*

made the front end of American motor cars excessively heavy; at the same time the possibilities have not been overlooked in this country and the aim on both sides of the Atlantic is to produce lightweight engines of higher efficiency having the pistons running direct in aluminium bores. The initial cost for the mass production of aluminium cylinder blocks is likely to be high, but increased "know-how" should result in satisfactory economics, having regard to the close dimensional tolerances which can be maintained in the castings as compared with cylinder blocks in grey cast iron, and that it is possible to core out many holes which at present have to be machined. It is probable that early supplies of aluminium cylinder blocks will be gravity die-cast. The advent of new refining processes has made hyper-eutectic silicon alloys of immediate interest, although it is possible that surface treatment may be required to provide the necessary frictional characteristics.

Aluminium panelling of motor car bodies has been used from the relatively early part of the period under review, although primarily in the high priced car field or in the commercial vehicle trade; this is due not only to the higher relative cost of aluminium and aluminium sheet as compared with steel sheet, but also to problems which arise in fabrication and in paint finishing, both of which incur added capital and production costs. In the commercial vehicle market, aluminium for panelling and for vehicle framing has been virtually a necessity in order to provide an economic pay load.

Aluminium bearings have been used to a limited extent in the cast form for many years on the Continent, but the development of bi-metal steel-backed aluminium alloy bearings is relatively recent and is largely a British development; such bearings possess performance characteristics approximately mid-way between those of tin-base Babbitts and copper-lead bearings, having excellent fatigue resistance associated with an appreciably lower hardness than that of copper-lead bearings, making it possible to run relatively soft shafts successfully.

While there is no great difficulty in the production of satisfactory aluminium radiators, this application is uneconomic at the present time.

One interesting application of aluminium is the "silvering" of headlamp reflectors, in which a pressed steel shell is coated with lacquer, the reflective surface vacuum-coated with aluminium and the surface subsequently sealed with a clear lacquer, this type of reflector having replaced the earlier silver plated reflectors which had only a limited life.

Tin

This metal has been indispensable in the development of the motor industry as a constituent of bearing bronzes, white metal bearings, and of solders, and to a limited extent as a corrosion protective. The bulk of tin used has been as a constituent of the soft solders used in the manufacture of radiators and for lead filling the bodies, to which reference is also made in the section relating to lead.

The most important engineering use of tin is in the bearing field, as a constituent of the many bronzes used for bushes and thrust washers, but principally in the white metal bearings used in the engine. Babbitt-lined bearings were in use prior to the First World War, the white metal being statically die-cast into heavy bronze shells; the lining was of considerable thickness, as it was considered that this provided an adequate degree of alignability and embeddability. About 1920, centrifugal lining direct into connecting rods was first adopted and die-cast as well as centrifugal-cast shells are still being produced.

Steel shells were introduced to replace phosphor bronze or gunmetal shells about 1928, and continuous casting of bi-metal strip commenced about 1934. At the present time, the majority of white metal bearings used in the motor industry are produced from such strip by cold forming and subsequent machining. The introduction of continuous cast strip was coincident with the adoption of thin shell bearings, with a lining thickness of about 0·02 in.-0·03 in. but micro bearings as used at the present time with a lining thickness of 0·004 in.-0·007 in. were not introduced until about 1948. Apart from the economics of the thinner linings the bearings provided much greater resistance to fatigue, any flexure occurring in service producing a much smaller stress in the lining than is the case with a heavy lining. The reduction in lining thickness was, in general, associated with reduced shell thickness, so that whereas from 1925 shell thickness ranged from $\frac{1}{4}$ in. to $\frac{1}{2}$ in., and in some cases down to $\frac{1}{8}$ in., this was reduced to a maximum of about 0·100 in. in 1934 with the advent of the continuously cast bi-metal strip, and for the current "micro" bearing the shell thickness is even less.

In the past, a certain amount of tin has been used as a constituent of the coating of terne plate used for petrol tanks; an appreciable amount of tin is employed as a constituent of solders for electrical connections and to a steadily reducing extent for other soldered joints, the tendency being to replace soft solders with hard solders wherever there is danger of stressing. One widespread and extremely valuable application of tin, even though consumption of the metal is infinitesimal, is its direct deposition by chemical substitution on the surface of the aluminium pistons, where its low hardness and low frictional characteristics enable successful running-in to take place without pick-up occurring between

the piston and cylinder bore; the alternative is to anodize the piston surface.

Zinc

The early use of zinc was confined to its incorporation as an alloy constituent in brass and related alloys, but since the introduction of the pressure die-casting process it has found increasing use for lightly stressed engineering applications such as carburetter and fuel pump bodies and for body hardware, such as door handles and hinges, and for decorative items such as grilles and body mouldings; it is interesting to note that carburetter bodies in zinc alloy were produced as early as 1920, although it was many years before it found widespread use for this purpose.

The primary reason for the widespread adoption of zinc alloys was their good casting properties, and the ability to produce intricate shapes to close tolerances; the economic production of these castings resulted from the relatively low melting point of the metal, giving long die life. The excellent casting finish and the close tolerances which can be maintained made little or no machining necessary, and the ability with which steel inserts could be cast in position was an added attraction. The very great attraction of pressure die-cast zinc alloy components can be appreciated if consideration is given to the fact that 60 per cent of the total production is absorbed by the motor industry.

Zinc has also found considerable use as a protective coating for the various forms of fasteners used by the motor industry; in the early days of the motor industry, most of the bolts used were purchased in either the bright or black oxidized condition, any protection arising from a surface film of oil, but this was subsequently replaced with sherardizing for bolts subjected to particularly corrosive conditions, and this has now given way to the general application of electro-deposited zinc. Zinc plating for protective purposes is also applied to door lock mechanisms, although as a matter of convenience such protection may also be provided by tin or tin alloy coating.

Zinc is also used to a limited extent as an interleaving material for leaf springs, in order to provide greater service life by virtue of the sacrificial protection it affords against corrosion and to the reduction which it promotes in the frictional effects between the spring leaves; it is also extensively used in zinc dust welding primers, the zinc dust providing corrosion protection along the welded joints, the conductivity of the metal particles making welding possible.

If equivalent results, particularly from the economic aspect, could be obtained with pressure die-cast aluminium alloys suitable for bright anodizing to give a highly reflective surface, the use of zinc die-castings for bright trim items and body hardware which are finished with an electro-deposit of nickel and chromium would wane.

Lead

In the early part of the period under consideration, when the body structure was a composite of wood and metal, the use of lead was limited to its incorporation in solders for the construction of such components as radiators and lamps, and its incorporation in brass for the promotion of free machining properties. The introduction of the storage battery in 1910 for the lighting system increased the usage of this metal very considerably, and the consumption was still further raised by the introduction of the all steel body in the mid-1930's, necessitating the use of solder for the filling, popularly known as "lead loading", of external welded joints, in order to provide an unbroken surface for subsequent painting.

The early petrol tanks of motor cars were made of tin plate, but over the years this changed to terne plate, and at the present time the majority of motor cars have petrol tanks produced from uncoated steel, their external surface being adequately protected by an organic finish, and the internal surface requiring no protection; it is possible that the satisfactory life now obtained with uncoated steel is due to the better control of the quality of the supply of the fuel, but where petrol tanks have to be stored prior to assembly the internal surface does have to be protected against atmospheric corrosion by coating it with some form of temporary protective. A further reason why either tin- or terne-coated sheet was originally used lies in the fact that the petrol tank was a soldered assembly, whereas the modern fuel tank is of welded assembly and coated metals are not the most desirable material for this method of fabrication, owing to fouling of the electrodes by the protective metal coating, and additionally the protective value of the coating is impaired in the vicinity of the welded joint.

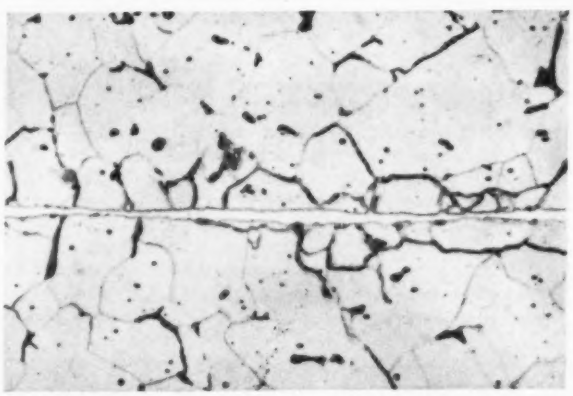
The most recent use of lead is for copper-lead bearings, which have already been referred to in the section relating to copper; the lead content of these bearings ranges from 20-40 per cent, and they have an additional plated overlay of either lead-tin or lead-indium alloy to provide a satisfactory surface for initial running, and also give protection against corrosion from organic acids in the lubricating oil resulting from the effects of combustion.

The most consistent use of lead over the years, apart from the battery, has undoubtedly been as solder for the radiator block; in this assembly, for which dip soldering is employed, the majority of the solder used occurs as a coating for the whole assembly, only a proportion being actually necessary for the jointing requirements. A further considerable use of lead is for the soldered joints in the many electrical connections.

Magnesium Alloys

Experimental work on the adoption of magnesium alloys by the motor industry commenced in 1925, and the material was adopted for engine sumps by London Transport in 1930; it can therefore be regarded as a comparatively new metal in the motor industry, and its consumption is still relatively low. It is more extensively used for commercial vehicles than in the private car side of the industry, owing to the necessity for keeping dead-load at a minimum, so achieving maximum pay load; its use for motor cars has been somewhat spasmodic, depending upon the relative cost of magnesium and aluminium alloys as castings. Thus, although the basic price of magnesium alloys might be higher than that of aluminium alloys, the price of the component could well be lower owing to the lower density of the material. One disadvantage of magnesium alloys is their relative corrodibility, making special surface treatments necessary, but it would appear from experience that corrosion is somewhat less of a problem than was at first feared, and there is little doubt that magnesium alloys could well have a great future in the light car field, if due consideration is given to its lower modulus of elasticity and

Fig. 8—Section through "Bundy" tubing ×500



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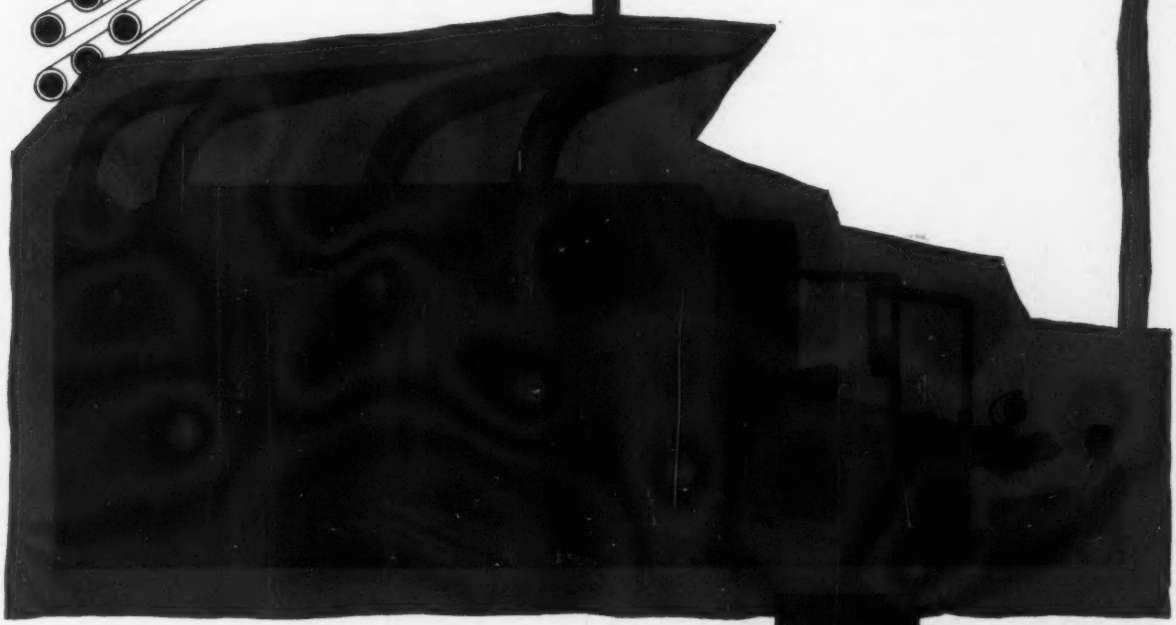

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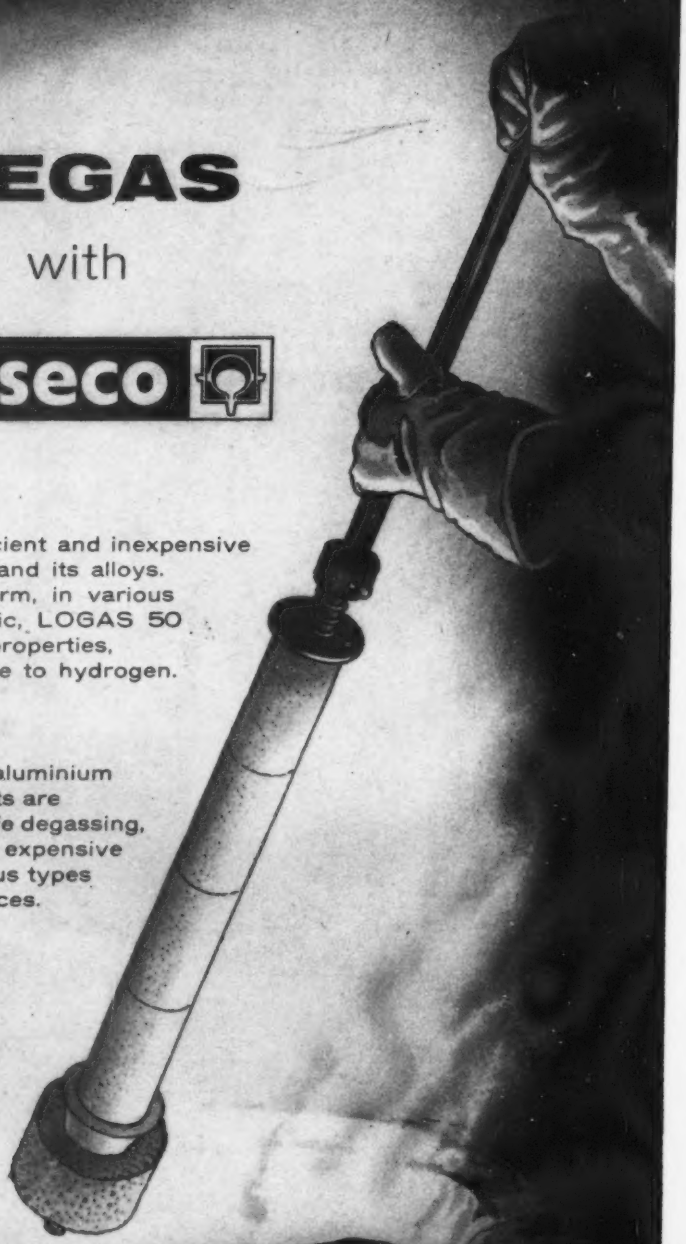

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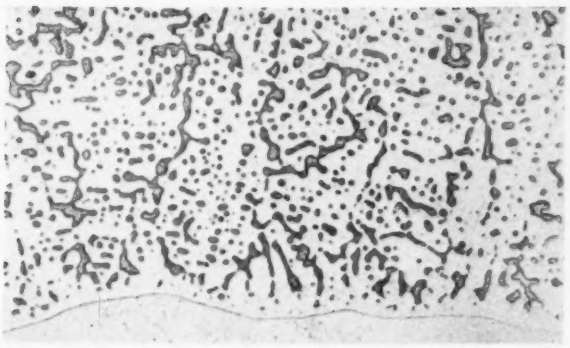


Fig. 9—Microstructure of statically cast copper-lead bearing ×120 *(Courtesy Glacier Metal Co.)*

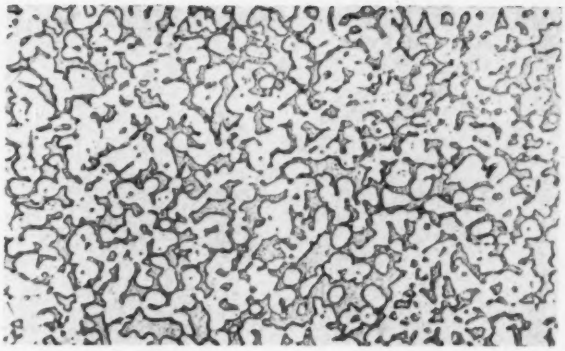


Fig. 10—Microstructure of sintered copper-lead bearing ×120. *(Courtesy Glacier Metal Co.)*

higher co-efficient of expansion, as compared with aluminium alloys.

Magnesium is, of course, widely used as an essential alloy constituent of the majority of the high-strength heat-treatable or corrosion-resistant aluminium alloys.

Nickel

This versatile metal is so widely used as an alloy constituent of both ferrous and non-ferrous materials that reference here will be confined to its use either in its own right or to its use in non-ferrous materials. It has made a very great contribution to the success of the motor industry, owing to its effect in promoting greatly improved mechanical properties in both ferrous and non-ferrous alloys; possibly its earliest use in the motor industry was as nickel silver for body hardware items, although brass and brass plated fittings were in vogue until 1915. This brass finish was replaced by nickel, as an electro-deposit, at a very slow rate during the period 1915-1922, being applied as a dull deposit requiring mechanical polishing, and subsequent maintenance by the car owner to retain its early lustre. From 1922 nickel-plated radiator shells became standard fittings, and the deposit was subsequently enhanced by the advent during the period 1924-1928 of a chromium overlay, and to this present day the motor industry is the largest single user of nickel, much of this being employed in the form of nickel-chromium plating of steel, brass, and zinc die-cast trim items. Although its position is now being seriously challenged by competitive materials, such as stainless iron and anodized aluminium, for trim items, the obvious advantage of nickel-chromium plating is the extremely reflective and highly scratch-resistant finish which is obtained.

Nickel as a constituent of non-ferrous alloys is somewhat limited on the average car, but for high performance cars it finds use as an alloy addition for valve seat inserts, and valve guides for light alloy engines. Any considerable increase in the future use of nickel will undoubtedly be related to the further development of the turbine engine; in these, nickel-containing alloys are essential in order to obtain the necessary hot strength and creep resistance and the well known Nimonic series of alloys and others fulfil these requirements. The future of this type of engine in the motor vehicle field is related to the development of an economic but efficient heat exchanger of reasonable size to cope with the large volume of gases involved. One very important use of nickel is for the electrodes of sparking plugs, and on some of the higher priced cars, and for special wheel finishers it finds use as a constituent of austenitic stainless steel.

Decorative Plating

On the early motor car, attractiveness was achieved by the use of brass and copper fittings. In time, these relatively expensive fitments were in part replaced by steel forgings and to achieve the desired appearance were brass plated, but over the years this finish gave place to composite deposits of copper and nickel, or nickel alone, the necessary lustre and maintenance of brightness being obtained by continual care on the part of the owner. . The introduction of chromium plating as an overlay for the nickel ensured intense reflectivity and little maintenance. Whereas early electro-deposits on trim items comprised a nickel flash followed by copper which was buffed, then nickel, also buffed, and finally chromium, improvements both in the standard required by the motor car manufacturer and by the customer, and by the necessary improvement in the economics of the processes has seen the development of bright nickel deposits as undercoats, and of semi-bright undercoats which require only light buffing. The value of a copper layer as a protective medium has long been in doubt, its main attraction being the ease with which it could be buffed, and provided it was followed with an adequate thickness of good quality nickel all was well; when the nickel coating has to be buffed, there is always the danger of it being locally thinned and this has resulted in the widespread interest in the duplex coating consisting of semi-bright nickel followed by a fully bright layer to provide the necessary smooth and reflective surface, the absence of buffing ensuring an adequate and uniform thickness of undercoat. The adoption of a chromium overlay to prevent tarnishing of the polished nickel coating has not, unfortunately, always prevented corrosion, largely due to the impossibility of depositing an adequate thickness of chromium free from cracks; the recent introduction of crack-free chromium deposits, applied in somewhat heavier thicknesses than for normal chromium, undoubtedly provides a solution to at least some of the problems which have arisen in the past with chromium-plated trim on motor cars.

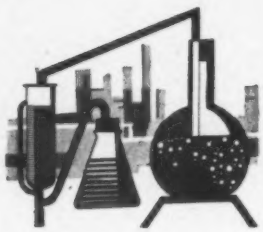
Conclusion

This survey of the use of non-ferrous metals by the motor industry during the past 50 years is not claimed to be exhaustive, and there are many omissions of non-ferrous metals used to only a limited extent, such as the inclusion of silver in radiator brass and in solders, platinum for electrical contacts and others. Although these materials have made their own valuable contribution to the success of the motor industry, interest must necessarily centre on those metals and alloys constituting the greatest tonnage employed.

The writer acknowledges a debt of gratitude to friends in associated industries, to the various Development Associations and to colleagues within the British Motor Corporation, who are too numerous to mention by name, for help in the provision of background information, and acknowledgments are paid to the directors of the British Motor Corporation for permission to prepare this article.

1909 - 1959

NON-FERROUS METALS IN THE



Chemical Industry

by J. B. COTTON
A.R.I.C.
Head of Corrosion Section Research Department, I.C.I. Metals Division

HISTORIANS, reviewing events of the present century, may well find justification for concluding that industrial scientific progress in the first sixty years, stimulated by the advent of two World Wars, was as outstanding in its effect upon mode of living as was the Industrial Revolution of the eighteenth century.

The first decade of the twentieth century saw the commercial application of the contact process for the production of sulphuric acid from sulphur dioxide; it witnessed the establishment of the Haber process for production of

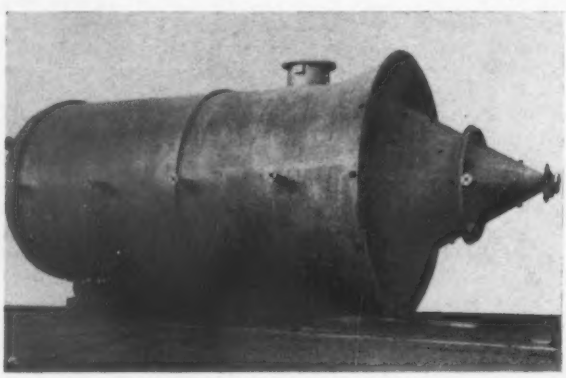


Fig. 1—Welded aluminium tank for use with corrosive liquids. (Courtesy Marston Excelsior Ltd.)

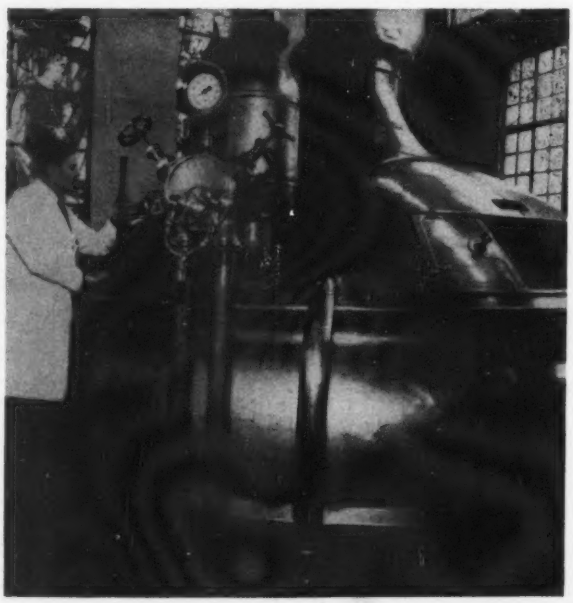
synthetic ammonia from atmospheric nitrogen, and the oxidation of ammonia to nitric acid by the Ostwald process. In that decade, too, Linde liquid oxygen was first produced from air and oxy-acetylene welding and cutting became economically possible. The sixth decade has produced the first commercial generation of electricity from nuclear fission, the first nuclear powered sea-going ship and the first probes have been sent into outer space. Between these two decades came the tangible evidence of scientific progress provided by the invention of man-made fibres, new dyes with which to dye them, synthetic rubber, the development of a whole new plastics industry, the jet engine and telecommunications. The future historian will not have to search too deeply to conclude that few, if any, of these spectacular advances could have become practical possibilities without equally conspicuous progress in the science of metallurgy.

The rapid developments in the chemical industry taking place at the beginning of the century directly followed practical applications of the new knowledge then being acquired concerning catalytic processes, particularly in respect of gas reactions. The fact that such processes often depend upon the presence of small quantities of finely divided metal, well illustrates the point that the importance of non-ferrous metals to the chemical industry is not necessarily judged by viewing lists of tonnages of metal employed.

Aluminium

It is an interesting exercise to trace some aspects of early metallurgical development alongside that of the expanding chemical industry. Thus, by the turn of the century, the electrolytic method of Hall and Heroult had cheapened aluminium, which was then being produced at a level of between five and ten thousand tons per year. By 1909 Wilm had discovered age-hardening and opened the way to heat-treatment as a means of strengthening aluminium alloys, and in 1923 Bengough and Stuart introduced anodizing. Thus, by the early 1920's when nitric acid had become more easily available by the advent of ammonia oxidation, when demand for acetic acid needed in the rayon industry was being satisfied by the newly developed method of oxidation of acetaldehyde, and when hydrogen peroxide had become more easily available from sulphuric acid by the electrolytic route, aluminium was ready to provide the means whereby ready

Fig. 2.—Brewery "copper" belonging to Courage & Barclay Ltd., London. (Courtesy Copper Development Association)



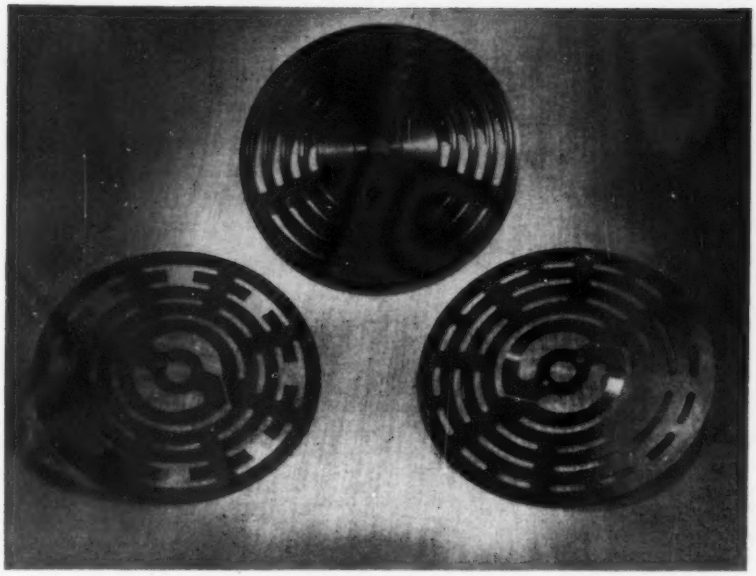


Fig. 3—*Hoerbiger-type compressor valve assembly in titanium and titanium alloy.* (*Courtesy Compressor Accessories Ltd.*)

bulk storage and transport of these three important raw materials could be achieved. A typical welded aluminium tank used for the containment of corrosive chemicals is illustrated in Fig. 1.

Since the early days of the century, development of aluminium alloys has progressed mainly in the direction of providing increased strength without undue impairment of corrosion resistance. To-day, the chemical engineer has a useful choice of aluminium-base materials ranging in strength from about 4 tons/in^2 to 30 tons/in^2. The addition of small quantities of manganese or alternatively magnesium provides him with a series of non-heat-treatable alloys that can be readily worked and are easily welded, while the inclusion of one per cent each of silicon and magnesium makes available a heat-treatable alloy with a strength to weight ratio better than that of mild steel.

The purity of a product is a matter of great importance to the industrial chemist, and particularly in the foodstuffs, pharmaceutical and dyestuffs industries, a strict control is exercised upon the heavy metal content of the finished product. In these industries aluminium is valued because traces of aluminium corrosion products are colourless, non-toxic and they do not usually produce undesirable side effects. For example, unlike most heavy metal salts they do not cause decomposition of hydrogen peroxide now being increasingly employed as a rocket fuel and, in petroleum refining, they do not catalyze gum formation in furfural used as a purification agent.

Aluminium is eminently suitable for the handling of very pure water used in increasing quantities in the chemical industry; it is indeed being used at moderate temperatures in the heat exchange circuits of water-cooled nuclear reactors, and special alloys containing nickel and iron are under development to enable its use to be extended in pure water at temperatures of the order of 250°-350°C.

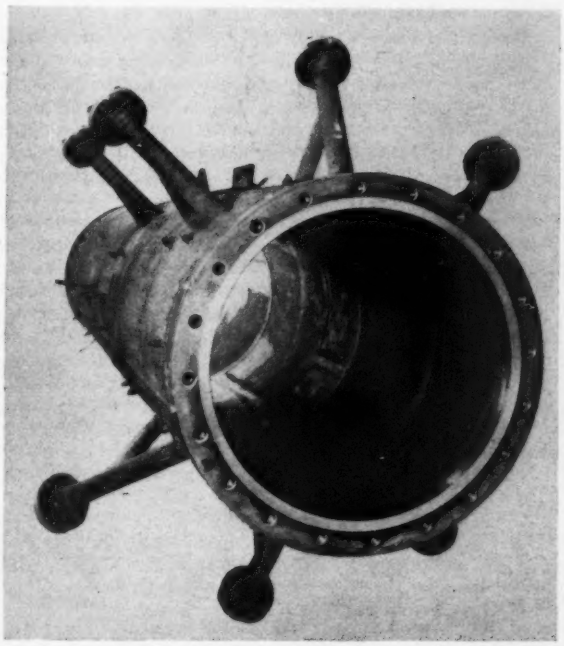


Fig. 4—*Titanium-lined reactor vessel with branch pipes*

Lead

The containment of strong acids both during and after manufacture has always constituted one of the most difficult problems for the chemical engineer, and, in contrast to the many new materials of construction developed over the last fifty years, it is interesting to reflect that sulphuric acid, the oldest product of our scientific chemical industry, is still widely handled in lead which surely must be the oldest metallic material used in any chemical process. Lead was employed in the form of salt pans, by the Romans, but its valuable corrosion resistant properties were virtually overlooked until about 1750, when Roebuck, at Birmingham, frustrated by size limitations of glass, turned to lead chambers for his sulphuric acid plant. A useful degree of improvement in corrosion resistance and in strength of lead has been achieved over the past fifty years mainly by attainment of higher levels of purity, coupled with addition of

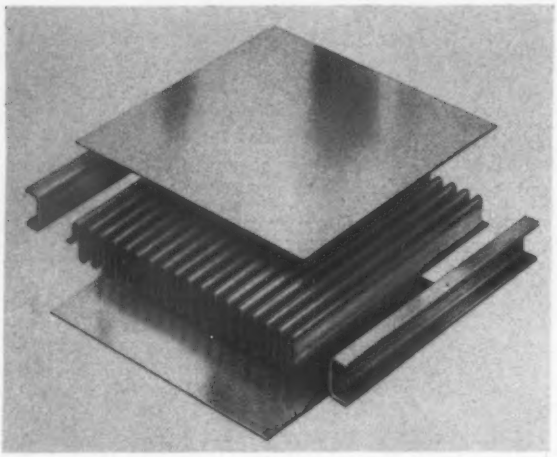


Fig. 5a—Method of construction of aluminium secondary surface heat exchangers, fabricated by the furnace or bath brazing techniques. (Courtesy Marston Excelsior Ltd.)

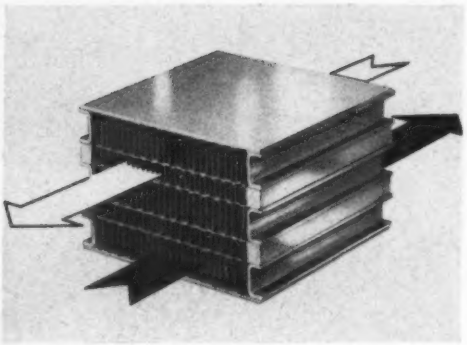


Fig. 5b—Elements assembled to form a contra-flow arrangement

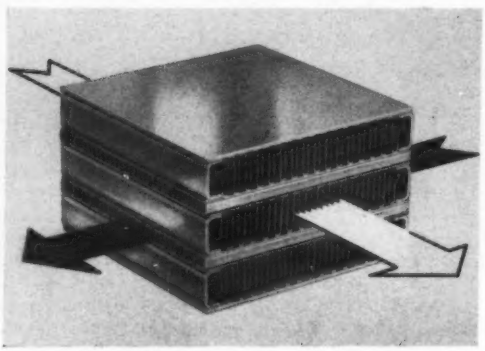


Fig. 5c—Elements assembled to form a cross-flow arrangement

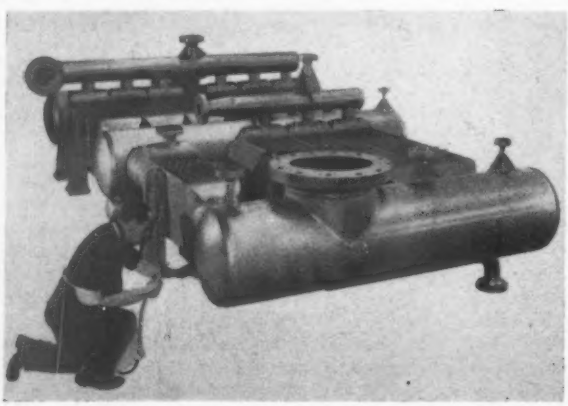
small quantities of either copper, silver and tellurium, or combinations of these.

Copper and its Alloys

Because it possesses a high ductility and low rate of work hardening copper is fabricated, without heating, more easily than most structural metals and in consequence over the past fifty years it has become traditional material in the construction of the complicated shapes required for reaction vessels, kettles, stills and fractionating columns, particularly in the field of organic chemistry. A large copper pan used in the brewing of beer is illustrated in Fig. 2.

Whether the ultimate product be a strong liquid acid or less aggressive neutral plastics material, at some stage or other many of the chemical processes now operated involve a gas reaction and it is in the handling of hot gases that copper-base alloys with their good heat conductivity, render a most valuable service to the chemical industry. In the petroleum and petrochemical industry, particularly, conservation of heat in the distillation and condensation of vapours plays no mean part in the total economy of such processes and many hundreds of thousands of tons of copper-base tubes have been installed in the now almost traditional shell and tube heat exchanger.

Fig. 6—Industrial secondary surface heat exchanger in aluminium for oil refinery use. (Courtesy Marston Excelsior Ltd.)



Research and development of the alloys used in this type of equipment already spans fifty years and is still continuing. The main emphasis has been upon improvement in resistance to corrosion and erosion by impure industrial cooling waters. At the beginning of the century, materials available in tube form were limited to copper and brass, and the really first incentive to improve upon these had its origin in the fact that corrosion—mainly in the form of dezincification of brass condenser tubes—nearly immobilized our naval forces during the 1914-1918 war. Some improvement was achieved by the addition of 1 per cent tin to 70/30 brass, to give Admiralty Brass, but the problem of dezincification of alpha brass remained until the discovery about 1920 that the addition of about 0·05 per cent arsenic effectively restrained this form of corrosion. The next significant step forward in the copper alloy field came with the discovery at the British Non-Ferrous Metals Research Association that 2 per cent of aluminium to alpha brass would significantly increase resistance to erosion. By this time, 70/30 cupro-nickel was already known, but it was to benefit significantly from the addition of iron and manganese. Subsequently, for economic and strategic reasons, two further alloys containing 10 per cent and 5 per cent of nickel respectively were produced for moderately arduous service.

Most of these developments have been mainly directed to improving performance in steam condensers, but when, after the Second World War, there came a very large expansion in home refining of crude oil and in the inter-connected petrochemical industry, these materials were readily available to satisfy the demand. Although appreciable tonnages of copper, 70/30 brass and Admiralty Brass tubes are still employed, many chemical engineers are taking advantage of the superior corrosion-resistant properties of aluminium brass and cupro-nickel. Where mildly acid conditions are encountered, either on coolant or product side, aluminium bronze often gives good service.

Virtually no chemical plant can function without the means to pump and control flow of liquid, and from the copper-base alloys phosphor bronzes containing 10-12 per cent tin, and up to 0·25 per cent phosphorus, gunmetals containing 8-10 per cent tin and 2-4 per cent zinc are readily cast. With addition of a little lead they are easily machined into the intricate shapes required for pump impellers and casings, and for valves and cocks. These alloys are reasonably resistant to corrosion and erosion in mildly acid and mildly alkaline media, and they are an essential material of construction in many chemical plants.

Nickel and its Alloys

The considerable progress that has been made in the development of nickel alloys over the past fifty years probably gives a better indication of their usefulness to the chemical industry than the tonnage employed would indicate. The development of nickel alloys started about 1905, when Ambrose Monel in Canada suggested the direct smelting of an ore containing approximately two-thirds nickel and one-third copper together with small quantities of iron and manganese. He thus gave his name to an alloy having excellent resistance to corrosion combined with good mechanical properties.

The addition of silicon enables this alloy to be fairly easily cast, while by adding about 4 per cent of aluminium it can be thermally hardened. These alloys are all fairly resistant to most non-oxidizing acids of moderate strength, while a more recent modification containing about 2·8 per cent molybdenum, 6 per cent iron and small quantities of copper, silicon and manganese has high resistance to non-aerated hydrochloric acid. A further alloy containing about 13 per cent chromium is moderately resistant even under oxidizing acidic conditions.

A series of alloys containing between 60-80 per cent nickel, together with varying proportions of molybdenum, iron, chromium, and tungsten, although limited as to the extent to which they can be worked into shape, has proved most valuable in their resistance to hot sulphuric acid. Some grades of this form of material resist attack in hot sulphuric acid even in oxidizing conditions, whilst other forms are also moderately resistant to hot hydrochloric acid.

Although not yet extensively employed in the chemical industry mention must be made of the complex alloys based on high nickel-chromium compositions. These have excellent resistance to oxidation and good creep resisting properties at temperatures within the 800°C.-900°C. range, and without them the jet engine could never have reached its present state of development. Some forms of this type of alloy have already proved of value to the chemical industry as furnace tubes and as conveyor belts for high temperature service.

It is, however, in their excellent resistance to corrosion by caustic alkalis that nickel and its alloys are best known to the chemical engineer, and over the past fifty years many thousands of tons of caustic liquors have been processed in equipment constructed of, or lined with, nickel.

The comparatively high cost of nickel has undoubtedly restricted its use, but the intrinsic corrosion resistance of this metal and the attractive mechanical properties are utilized in a host of small but essential components, and especially in the vital instruments that constitute the pulse of a chemical plant.

Present and Future Trends

The jet aeroplane, the rocket and nuclear power developing rapidly over the last ten years have presented the metallurgist with an unparalleled opportunity to produce new materials to meet increasingly exacting demands. Developments in the field of aviation demanding a high strength to weight ratio in materials of construction, provided the incentive which resulted in the production of titanium and the advent of nuclear energy makes it necessary to produce zirconium, niobium and beryllium. Without exception these metals, now becoming newly available in quantity, possess such a strong affinity for oxygen that they have required novel methods of melting—usually under high vacuum or under argon. They have also brought forth specialized techniques of fabrication. Indeed, in a very short space of time several new chapters have been added to metallurgical knowledge and techniques.

In the chemical industry good use is already being made of the excellent corrosion and erosion resistant properties of titanium. Mention has already been made of the necessity of maintaining metallic contamination at a very low level in some chemical processes. This arises in order to retain efficiency in catalytic processes, to meet a rigid pharmaceutical requirement, to prevent discoloration and even, on occasion, to ensure a low neutron absorption level in a product. In some chemical processes carried out in conventional equipment, it is even necessary to include a special purification stage to rid the final product of traces of heavy metals. In many chemical plant environments corrosion resistance of titanium is so high as to meet these stringent requirements and use of the metal in the early stages of manufacture can eliminate a complete purification step at a later stage.

It is almost certain that there will be occasions when the development of a novel chemical process will be dependent upon the existence of one of these newer metals. An example already exists in the modern chlorite bleaching process for textiles. This requires a robust plant with a high proportion of moving parts, all of which have to be resistant to the very aggressive chlorine dioxide. Titanium possesses excellent resistance to this environment and it is very doubtful whether, without titanium, chlorite bleaching could become a commercial proposition.

Titanium is very resistant to conditions of metal fatigue and corrosion fatigue, and apart from its use in massive chemical plant, it is being applied to the construction of small but vital components, failure of which could result in stoppage of a complete process.

One outstanding use, for example, is in the valve plates of gas compressors. These are subject to a high level of reciprocating stress and the titanium valve plate illustrated in Fig. 3 has outlasted conventional materials by a very large margin.

In looking to the future, mention must be made of a method of protection known as anodic passivation, particularly appropriate to such metals as titanium. Adoption of this system promises to widen the scope of use of such metals when in contact with strong non-oxidizing acids. By way of example, it is now known that by slightly raising the electrical potential of titanium by connection to a D.C. battery, titanium can be completely protected against

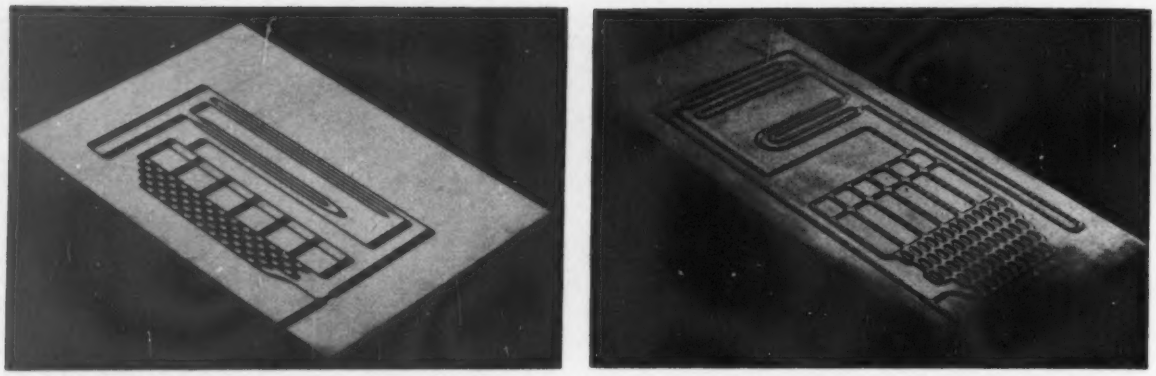


Fig. 7—Roll bonded aluminium sheets. Left: Stop weld pattern printed on sheet prior to sandwiching and rolling. Right: Rolled and inflated sheet

corrosion under immersed conditions in sulphuric acid, even in the intermediate concentrations of 20 per cent, 40 per cent and 60 per cent, at temperatures as high as 80°C.—conditions which attack virtually all other constructional metals save lead and silicon iron.

Moving up the scale in corrosion resistance from titanium there are zirconium, niobium and tantalum, all becoming increasingly useful as the acids become more and more aggressive. Tantalum is now well known for its unique resistance to any strength of hydrochloric acid, at all reasonable temperatures and in the presence of air or otherwise. As a result of the development of new methods of production, coupled with demands from other fields of use, all these metals may be expected to become less costly and in consequence they will take their place more frequently amongst the materials of construction available for special purposes in the chemical industry.

Advances in Fabricating Techniques

No account of the part played by non-ferrous metals in chemical engineering would be complete without reference to the considerable advances made over the past fifty years in fabricating techniques.

As far as welding and brazing alone are concerned, there has been more progress than in almost any other branch of metal technology. Prior to the last twenty years, welds in non-ferrous metals had been made by the gas welding, by metal arc and by carbon arc techniques which had been used over the previous thirty years, and which had proved successful for ferrous materials. The production of good welds in non-ferrous metals by the same means is not an easy matter, and it was not until the development of the argon-shielded metal-arc weld that there was any real progress. It is certainly no exaggeration to say that the increased and increasing use of aluminium in the chemical industry over the past ten years would not have been possible without the advent of argon-arc welding. With a relatively expensive metal such as titanium, techniques of lining mild steel with thin titanium sheets are a very recent innovation and here it is necessary to use argon shielding on both sides of the weld —a process which was unknown even ten years ago. A large mild steel vessel lined with welded titanium sheet is shown in Fig. 4.

Fig. 8—Roll bonded heat transfer sheets in aluminium. Completed panel ready for installation

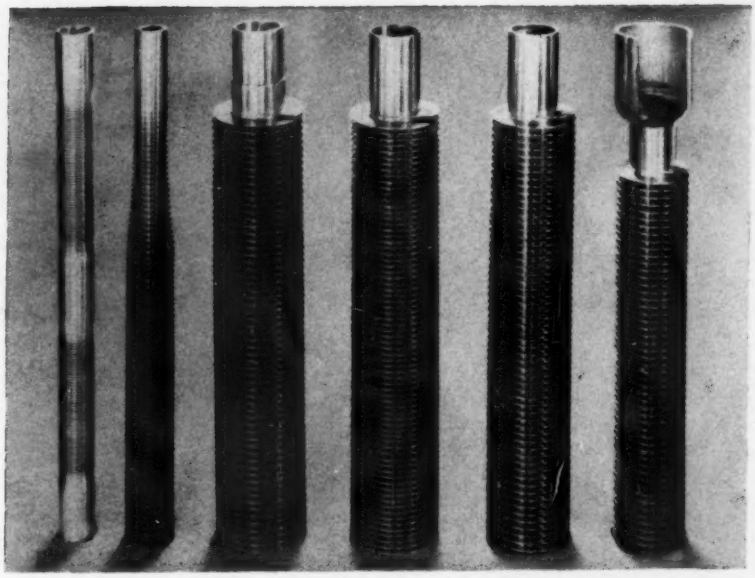


Fig. 9—Examples of different types of Integral tubing the fins being worked up from the tubing itself

Probably the most significant advance in brazing non-ferrous metals concerns the fabrication of equipment such as secondary surface heat exchangers by either the furnace brazing or the flux bath technique. These units are assembled from tiers of thin crimped or formed sheets which either carry an integral coating of brazing alloy or alternatively are interleaved with thin sheets of brazing medium. The matrix of sheets, held in temporary clamps, is then either dipped into a molten flux bath or placed in a furnace and held at a temperature at which the brazing alloy melts and retracts into interstices formed by the crimping. The whole forms a very strong light block having excellent heat transfer properties. The detail of the construction of this type of heat exchanger is illustrated in Figs. 5 *a, b, c,* and Fig. 6 shows an industrial heat exchanger incorporating this system, and employed in a petrochemical plant.

Chemical engineers are always striving to increase the efficiency of heat transfer processes and there are three relatively modern forms of semi-fabricated non-ferrous products, likely to play a part in this important field. Roll-bonded aluminium consists of two sheets of the metal pressure welded together by rolling, but containing "stop-weld" passage ways (Fig. 7) that, when inflated, can carry either a coolant or heating medium. The resultant panel can be manipulated into a variety of shapes, one of which, for example, is already being used in refrigeration plant, as shown in Fig. 8. Tube in sheet, involving a similar idea of controlled laminations introduced during casting of the slab and subsequently inflated after rolling, is already available in copper and aluminium and its alloys. However, there seems no reason why other metals and alloys should not be adaptable to the same process. To date there has been only very limited use of this technique which could obviously provide a very fruitful field of development for the chemical engineer interested in efficient heat transfer. For example, this form of construction seems ideally suited for steam heated vats or reaction vessels, thus eliminating internal heating or cooling coils.

For some considerable time, engineers have been interested in the use of tube having an extended surface in the form of external fins. The fins may be soldered or brazed on to the tube, but there are now fabricating techniques by which the fins can be worked up from the tube itself to produce an integral extended surface construction. This arrangement provides a most efficient means of heat-exchange between a gas phase circulating externally over the extended surface and a liquid medium inside the tube. It is available in a range of copper-base alloys, as well as in aluminium and magnesium. When a single material of construction is incompatible with either the gas phase or the liquid a bi-metallic construction can be provided. Thus, the cooling of ammoniacal vapours by sea-water can be achieved by employing an inner tube of aluminium brass or cupro-nickel with an outer finned tube of aluminium. An example of the integral finned tube construction is seen in Fig. 9.

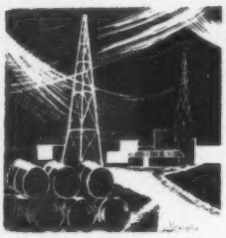
During the fifty years that have elapsed since the first appearance of METAL INDUSTRY the variety of operations performed in chemical plant has multiplied many times, efficiency of the processes used has improved by a very large margin, and the very appearance of chemical plant has changed out of all recognition. Today the emphasis is upon automatic and remote control and safety of operating personnel is an essential prerequisite of any modern design. It is not by mere coincidence that, in the same period of time, immense strides have been made in the technical production of metals and in fabricating techniques. In the current tonnage lists of metal production there are nine primary non-ferrous metals which were not deemed worthy of mention in the lists published fifty years ago, and in one form or another—as an alloy or by facilitating a novel construction—they have all contributed to the efficiency and safety of the present day chemical plant.

This has been a period of metallurgical exploration that is unlikely to be repeated in its wide scope. The number of new primary metals likely to come into future commercial production is limited; hafnium, yttrium and ductile chromium are already possible candidates, but there is little doubt future emphasis must lie in the direction of new and better alloys. That these will become available is also beyond doubt; there is an increasing demand for better and better materials of construction and a never-ending quest to satisfy the demand. For both the metallurgist and the chemical engineer, it would be difficult to find a more fitting quotation to conclude the present subject than the words Tennyson puts into the mouth of Ulysses:

"Yet all experience is an arch where through
Gleams that untravell'd world whose margin fades
For ever and for ever when I move.
How dull it is to pause, to make an end
To rust unburnish'd, not to shine in use."

1909 - 1959

NON-FERROUS METALS IN THE Oil Industry



by E. HARGREAVES

Corrosive Engineer, Mobil Oil Company Ltd.

FOR many years it was standard practice to use copper-base alloys for tubular coolers in which sea, estuarine or brackish water formed the cooling medium. Certain types of corrosion, however, were known to develop in these alloys, the worst of these was dezincification, and as long ago as 1890 the addition of 1 per cent tin, in place of 1 per cent zinc, in the 70:30 alloy was advocated as an attempt to cure this trouble. The inhibitive property of small percentages of arsenic, antimony or phosphorus against this attack, became one of the most important developments of the 1920's and the particular alloy—Admiralty Brass, containing 70 per cent copper, 29 per cent zinc, 1 per cent tin with 0·25 per cent of the inhibiting metal—was the natural choice for cooler and condenser tubing. This alloy is gradually being replaced in refinery equipment by aluminium brass composed of 76 per cent copper, 22 per cent zinc, 2 per cent aluminium with the usual addition of the inhibiting metal, especially where the coolant may contain large volumes of dissolved air. Should there be any small impediment inside the brass tube, a slight pressure drop is produced in the coolant across this obstruction with the result that dissolved air is liberated. The bubbles of air impinge against the internal surface of the tube and in the course of time, dependent upon the size of the obstruction, will penetrate through the tube wall. The aluminium brass has superior resistance compared to Admiralty Brass against air impingement attack by the formation of a more resistant film over the surface. Tube sheets formerly cast in naval brass—60:40—are now being superseded by aluminium bronze because of the superior mechanical strength and corrosion resistance of the latter alloy.

The use of copper tubing for instrument air lines is almost a standard item, but this material is now finding further application for steam tracing product lines in place of the once conventional steel piping. Whilst the initial cost of the copper tubing is greater than that of steel, the malleability of copper permits long lengths of tubing to be laid from coils, thus greatly reducing the installation costs.

Non-ferrous alloys of the copper-nickel type are finding increasing employment in heat exchangers where high temperatures occur and media of slightly acidic nature exist, or where the chloride content may be appreciable. The lining of the upper sections of crude fractionation columns with Monel metal has been carried out for crude oils particularly high in organic chloride compounds.

A relative newcomer into the oil industry in the sphere of non-ferrous metals is aluminium, and due to its particular properties, increasing attention is being given to this metal. Because of its light weight, aluminium is already well established in the U.S.A. in oil fields for the construction of portable derricks and drilling equipment. For refineries and in the transportation of oil products, the metal has recognizable advantages.

The insulation of tanks and piping has produced a field of unrivalled employment for aluminium cladding which has

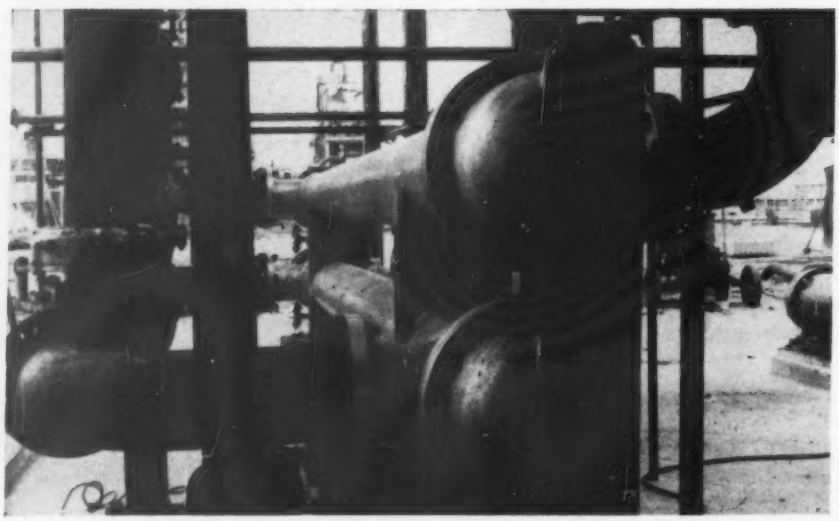


Fig. 1—*Channel ends and floating head ends of a pair of all aluminium coolers which form part of the gas purification unit at Mobil Oil Company's Coryton Refinery. Aluminium shells are employed with Noral* 65*S aluminium tube sheets into which are expanded Noral* 3*S clad aluminium tubes*

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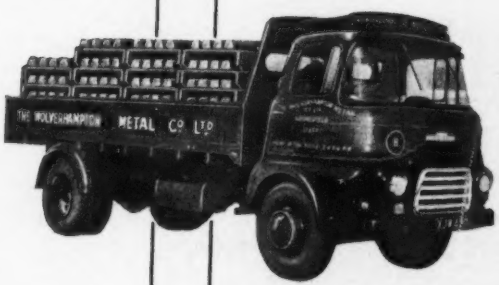

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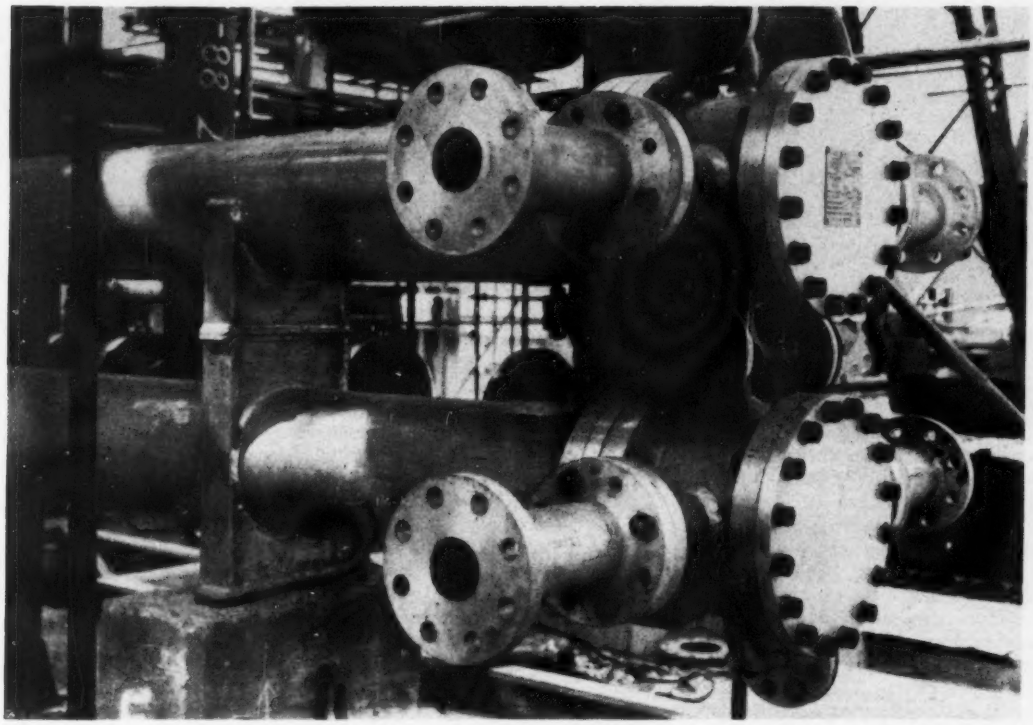


Fig. 2—Aluminium pipework for carrying wet hydrogen sulphide gas

proved equally resistant to marine and refinery atmospheres. Hundreds of gallons of aluminium paint are applied annually to give refinery units their characteristic silver appearance.

The resistance to corrosion of aluminium is, perhaps, the property which now attracts the attention of the refinery engineer. Its low mechanical strength once overshadowed this resistance, but by the addition of such elements as magnesium, silicon and manganese, this deficiency is being remedied.

The almost general use of sea water for cooling purposes has brought the corrosion resistant properties of lead into recognition, and the employment of this metal as a lining for the floating heads of closed coolers is becoming an extremely efficient competitor to the fabrication in copper alloy.

It is, therefore, evident that while steel is still considered the most general material of construction for oil refineries, the employment of non-ferrous metals commands quite a significant part in the building and maintenance of this industry.

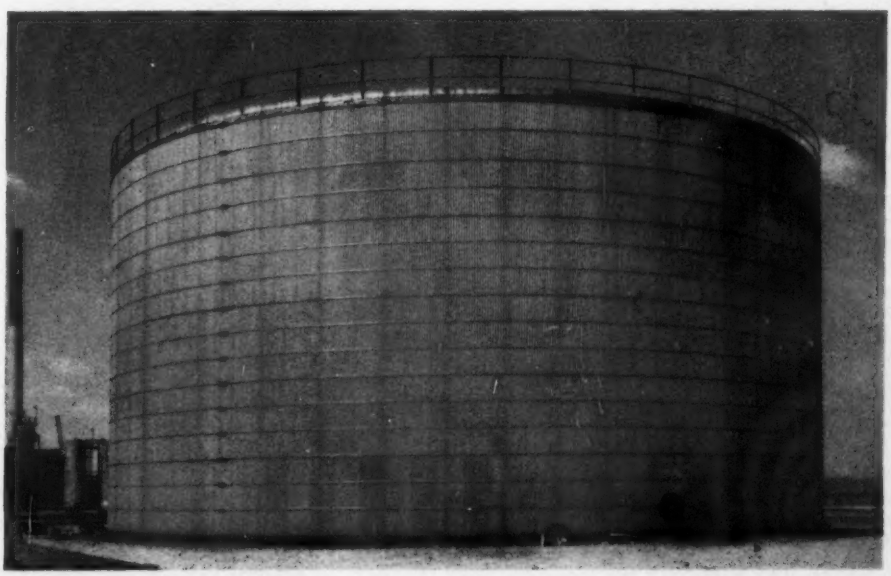
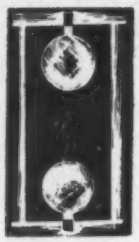


Fig. 3—Aluminium cladding for the insulation of oil storage tanks

1909 - 1959

NON-FERROUS METALS IN THE



Electrical Industry

by N. L. HARRIS
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Research Laboratories of The General Electric Company Limited, Wembley

WELLNIGH the entire development of the electrical industry from its modest beginnings to its present status of a major industry making important contributions to the industrial and civilian life of the world has taken place within the last 50 years. The broad scope of its activities, from prime movers, generating plant and heavy electrical equipment on the one hand to lighter equipment, domestic appliances and industrial heating on the other, necessarily involves the extensive use of metals. Many problems have been posed to the metallurgist and solutions found. By and large, the non-ferrous industry has been very co-operative with the electrical industry which, in its turn, has made significant contributions to the development of new materials for its own purposes. The value and the applications of these have not necessarily been confined to matters electrical. Furthermore, even a brief consideration of the anticipated rate of expansion of the electrical industry and of the technical problems which face it to-day, shows clear promise of equally important developments in the non-ferrous field in the future. Vast quantities of non-ferrous materials have always been required, from the earliest days, in general constructional work in the electrical industry. Of these, copper, brass and aluminium have been the most important and widely used, and this is likely to continue to be true for a long time to come. Extensive use is made of sheet metal, pressings, die-castings and plated finishes of many kinds.

Lamps and Lighting

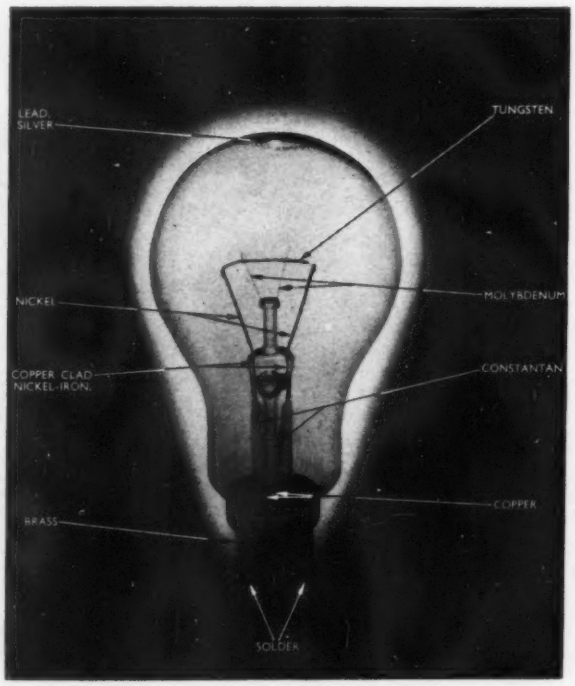
It is, perhaps, surprising to realize that the common tungsten filament lamp embodies ten or more non-ferrous metals in its construction.

In the earliest days, osmium and tantalum were used as incandescent lamp filaments. Tungsten, since then universally employed for this purpose, is amongst the most refractory of metals, difficult to prepare and to fabricate. The powder metallurgy process was first applied to making tungsten, and this is still the only practical way of founding it. Fifty years have seen no major changes in its technology but improvements have led to an ever-increasing consistency of manufacture, to better metallurgical characteristics and corresponding betterment of lamp performance. Molybdenum, the sister metal, less refractory but with a usefully high melting point, is important in furnishing the supports for the tungsten filament. Its use is vital as a mandrel material in the double coiling of the delicate tungsten filaments, for it is the only metal of adequate strength with a melting point high enough to withstand the temperatures reached in the heat-treatment of the coiled filaments prior to dissolving the mandrel. Both metals are used for making vacuum-tight lead-in connections when the characteristics of the lamp demand the use of a high softening point, hard glass, envelope.

Nickel is chosen for the internal leads to the filament and the clamps for the support of its ends. It has relatively low electrical resistance, is soft, and easily deformed in automatic machines to clamp firmly round the filament coil. The customary lead-in wire for the vacuum-tight lead-in seals through the normal pinched glass foot tube in general lighting service lamps is the copper-plated nickel-iron alloy known as "red platinum," which is balanced in alloy composition and copper thickness to give the correct axial and radial expansions necessary for these seals. Its name preserves the fact that platinum itself was once used for this purpose. Platinum is also currently used as a coating on molybdenum leads in quartz tubular "lamps" designed for infra-red heating purposes.

The external leads within the lamp cap are made of copper and include a short length of glass-clad "Constantan" wire (an alloy of copper and nickel) which provides a protective fuse. The shells of the caps are made from suitably ductile brass or aluminium and the lead wires are soldered to brass sole-plates with low melting point tin-lead solder, against which the contacts in the lampholder press.

Fig. 1—G.L.S. lamp with all non-ferrous metals indicated



In certain special types of lamp, used for projection purposes, a built-in reflector system is provided, with a silvered surface or, more usually, an aluminium coating put down by evaporation in vacuo. Similar aluminized coatings on lacquered steel pressings are being increasingly used on external reflectors, for example, in motor car headlamps.

In domestic lighting, the tungsten filament lamp has resisted many challenges and continues in widespread general use, but electric discharge lamps, which came into prominence in the thirties, have established themselves firmly and extensively in the fields of street lighting and industrial and office lighting. Basically, their construction involves very similar techniques to those employed for incandescent lamps in making vacuum-tight seals and supporting the internal electrode structures. The latter comprise coiled tungsten wire filaments, but these are now used to carry a thermionically emissive material instead of providing the luminous source. In general, therefore, the same non-ferrous metals are used for the construction of electric discharge lamps as for incandescent lamps, but others are required in addition.

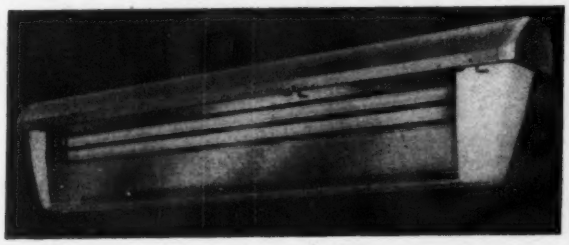
The thermionically emissive material makes use of compounds of calcium, barium, strontium and thorium. The light output is derived from the excitation of metallic vapours in the electrical discharge. Sodium gives its characteristic yellow radiation and mercury, in a state of high pressure, a bluish-white light. This latter can be modified and made whiter by the addition of cadmium and zinc. However, where white light acceptable for general illumination is required, a low pressure mercury vapour discharge is established and invisible ultra-violet radiation generated therein is converted to visible light through the medium of luminescent powder coated on the inside of the discharge tube. Similarly, such powders used on the interior surface of the outer envelope of a high pressure mercury vapour lamp will effect a very considerable degree of colour correction and yield an overall white light. The metal constituents of the many fluorescent compounds used comprise calcium, cadmium, magnesium, zinc, tungsten, barium, strontium, lithium and germanium.

Various specialized forms of discharge lamp, of considerable importance even if of limited application, make use of non-ferrous metals. Caesium and potassium are chosen as electrode emissive material in flash-discharge light sources. Standards of radiation are derived from other types of lamp, in particular from sodium, cadmium, thallium and mercury. In applications requiring extremely narrow spectral lines in the radiated output of the lamp, a single isotope of mercury is used as the filling.

Lamps must be operated in properly designed and constructed lighting fittings for full and effective use. Non-ferrous metals have always been employed extensively in their manufacture but the lighting industry has now turned to light alloys and plastics where it formerly used sheet iron, copper and glass.

Lanterns for exterior installations used to be made with copper spinnings, painted against corrosion, and lead-coated sheet iron. Silvered glass reflectors were incorporated when necessary. Effective life was long, and the all-copper lanterns on the Thames Embankment and Brighton Front, for example, are "still going strong" over 30 years after their installation. Copper is still used for some decorative lanterns, where low cost is not a decisive factor, particularly in seaside towns, and is believed to have the best corrosion resistance when properly employed.

Fig. 2—Electric street lighting lantern for three 5 ft. 80 W lamps, which is made from aluminium alloy



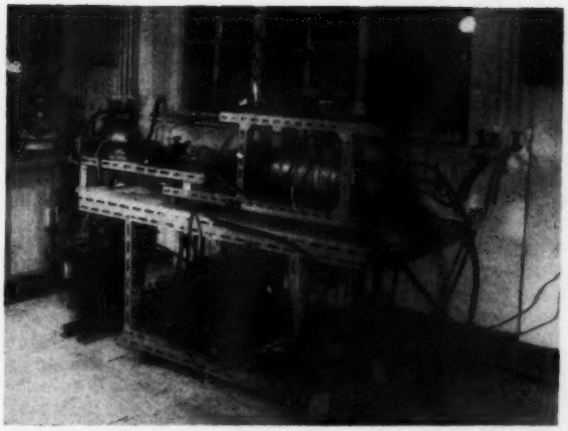


Fig. 3—Apparatus for the zone refining of experimental quantities of high-purity copper for studies of its basic properties

Concurrently with the growing use of plastics in place of glass bowls and refractors came the change to light alloys for the main body of the lantern. Precision die-casting and extrusion techniques lessen production costs by reducing machining and finishing processes. Very pure aluminium is used for optically reflecting surfaces, top quality reflectors demanding the use of metal with an impurity level as low as 2 parts in 10,000. It is only by the adoption of such techniques that elegant lanterns of sufficiently light weight can be manufactured in the large sizes now required. In many designs the body is an extrusion, fitted with die-cast ends.

Lightness of construction is essential in aerodrome installations, particularly on runways where there is the chance of impact of moving aircraft with lighting fittings and the consequent risk of serious accidents. It is not sufficient merely to provide a weak link in the mounting of the fitting: low mass is also essential. The use of pure aluminium for the combined reflector and body has solved the problem.

Interior lighting fittings in the past often used brass and this metal, or bronze, is still the basis of the more expensive and highly decorative models. The general run of inexpensive lighting fittings, however, is made from iron and a brass-plated finish is given for appearance.

Electronics

In the broad field of electronics, multitudinous applications are made of many kinds of thermionic valve and also of the semiconductor devices which are increasingly supplementing or replacing them. Events have moved far since the early days of the first Fleming valve in 1904 and Marconi's epic transatlantic transmission in 1901. Half a century of progress has seen the growth of a new electronics industry which makes widespread use of non-ferrous metals.

They are found extensively in valves of all classes as internal structures such as anodes, grids and cathodes. In the smaller valves used in domestic radio and television receivers, and in wide varieties of electronic equipment, the

anode is formed from nickel or aluminium-coated iron. The former is often carbonized to give it good heat radiating properties which are, however, inherent in the latter material. In the more expensive types of valve the grids are wound from molybdenum wire on nickel side rods, but in the cheaper valves alloys of nickel and manganese, or nickel, chromium and aluminium are used for the grid winding, these being mechanically stronger than the pure nickel employed formerly. Cathodes, both in wire and tubular shell form, are made from nickel or nickel alloys, a common additive being magnesium, which gives rapid activation of the thermionically emissive coating. An alloy with 4 per cent tungsten, possessing greater mechanical strength and having a favourably rapid reaction with the coating, is also used in the smallest types of valve. Indirectly heated cathodes have internal heating coils of tungsten or tungsten-molybdenum alloy, both of which have very long lives at the working temperature of 1,300° to 1,400°C. The older types of battery operated valve used an oxide-coated nickel wire for the cathode, but reduction of the heating current from 100 mA to 10 mA in the latest types has demanded a change to tungsten wire, which alone has adequate strength in the smallest sizes.

The pins which pass through the glass base of the valve are made from a nickel-iron alloy with an expansion matched to the glass. Operational requirements demand them to be short and strong; they plug into the valve socket externally and are connected internally to the electrodes either directly or via a short nickel strip. It should be noted that the choice of metals for the internal structure of the valve is somewhat restricted by the nature of the pumping and processing schedules, which call for baking temperatures of 400°C. This eliminates some of the cheaper metals and alloys which might otherwise be used.

Specialized miniature valves are now being made in which the grid winding wire is tungsten, which enables the wire diameter to be greatly reduced (e.g. from 0·05 mm. to 0·007 mm.) in order to obtain enhanced circuit performance. This very fine wire is wound on a stiff molybdenum frame, which is easier to work and weld than tungsten, and the turns are usually brazed in position with copper-gold alloy. When it is desirable to suppress the emission of secondary electrons from the grid, under electron bombardment, the molybdenum is gold plated.

By contrast with these small receiving types the large transmitting valves have a massive external copper anode which forms part of the envelope and is either air- or water-cooled. Normal commercial grades of copper are unsuitable for this purpose because of their volatile impurities and an oxygen-free, high conductivity grade of metal is essential. The absence of oxygen is necessary since processing techniques include heat-treatment in hydrogen to remove occluded gas from the metal, a technique which would lead to severe embrittlement of oxygen-bearing copper. The oxygen-free high conductivity metal used is made specially for the electronics industry.

When the anode is of more conventional form, within the envelope of the valve, it is often fabricated from molybdenum, tungsten or tantalum to meet the requirements of high power dissipation without distortion. Zirconium and titanium are coming into use and the latter is particularly suitable, with good mechanical properties and a valuable "gettering" action when hot. Zirconium also has a gettering action, but is less readily available and of inferior mechanical properties.

The manufacture of large transmitting valves often demands the fabrication of massive glass-to-metal seals, envelopes up to 1 ft. in diameter being joined to metal of the same dimensions. The earlier technique was to use copper with a feather edge of some 3° angle which yielded with changes of temperature sufficiently to take care of the large differences in expansion between the glass (6 to 10×10^{-6}/°C.) and the copper (16×10^{-6}/°C.). Such seals were strong but not robust. Alternative forms of seal were therefore developed using a 50:50 nickel-iron alloy whose expansion matches that of the glass, or a nickel-iron-cobalt alloy which matches a special hard glass made for it. Metal edges up to 1·5 mm. thickness can be used without undue residual strains in the seal, or discs of metal can be sealed between the ends of two tubes, but the thermal conductivity of the metal is only one-thirtieth of that of copper. This introduces complications in the problem of dissipating the heat developed during the operation of the valve.

In the microwave valve field there is an increasing use of ceramic envelopes in place of glass and this trend brings new problems in the manufacture of vacuum-tight seals. Several solutions have been found, the commonest being to fire a powdered alloy of molybdenum and manganese on to the ceramic and then attach the metal component by brazing with a low vapour pressure solder such as copper-silver or copper-gold. Alumina ceramic material has an approximate

Fig. 4—Five kilogramme high-purity single crystal of germanium being removed from the furnace in which it was grown. The crystal will later be sliced and prepared for use in various semi-conductor devices

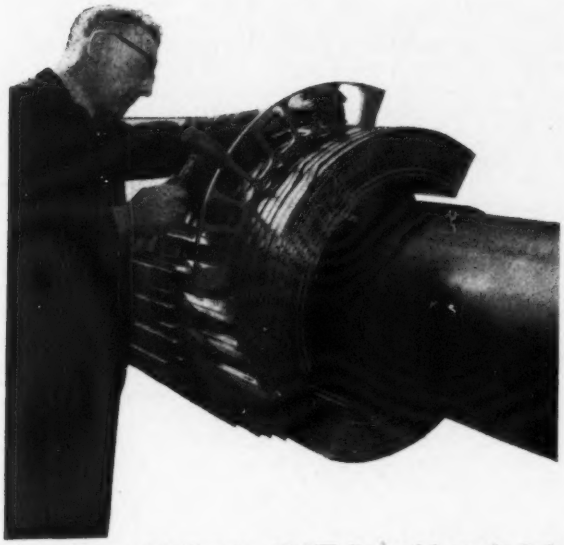


Fig. 5—Water-cooled Alternator. 60 MW direct-cooled rotor for Poole Power Station in course of winding. View showing winder inserting segmental packing block in end-windings at slipring end

expansion match to the nickel-cobalt-iron alloy. Titanium can be brazed to ceramic bodies with the same alloys without the use of the intermediate molybdenum-manganese layer because of its self-fluxing property. All these ceramic-metal constructions are exceedingly robust. The internal electrode structures are assembled with copper-silver, copper-gold and copper-indium solders and even with indium itself, but where the avoidance of volatilized conducting films is a matter of major importance, copper-gold or even copper itself is the preferred brazing medium.

The thermionically emissive coatings used in all types of valves comprise compounds of the same metals as those detailed for discharge lamps. Prior to this, in the earliest types of "bright-emitter" valve, the thermionic emission was derived from pure tungsten itself, followed by an intermediate stage of development in which the addition of thorium to the tungsten lowered the emission temperature and improved the efficiency. The latest development in some new types of valve uses a high emission density cathode made by impregnating a sintered tungsten matrix with barium aluminate.

The use of non-ferrous metals in cathode ray tubes follows the same general pattern of their uses in valves. Certain points of difference may, however, be noted. Operating temperatures of the electrode structures are lower, the magnetic properties of nickel forbid its use within the tube and certain metals, in particular copper, must be omitted in order to avoid contamination of the fluorescent screen by evaporation.

Semiconductors

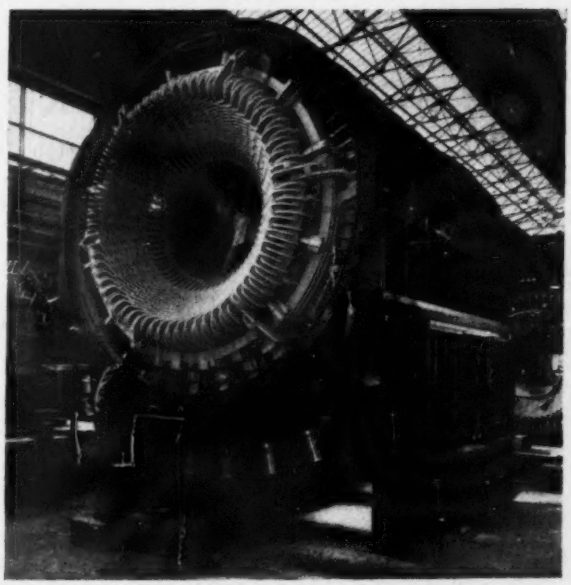
The past ten years have seen a remarkable growth of knowledge of the solid state and many practical developments of semiconductor devices—crystal valves—which not only replace thermionic valves but offer functional opportunities in new circuits which valves can never carry out. Semi-conductor materials lie half way between metals, in which an excess of electrons is free to move under the influence of an electric field, and insulators, in which the electrons are firmly bound to the atom. In a semiconductor the electrons are loosely bound and their movement in an electric field can be finely controlled. Some semiconductors exhibit a deficiency of electrons and the positions which are empty are known as positive holes. Movement of a loosely bound electron into one of the empty positions can be interpreted as the reverse movement of the positive hole. By a handing-on process, the resultant apparent motion of the positive holes plays an important part in supplementing electron conduction in a semiconductor device.

Although not strictly metallic in their properties semiconductor materials should not be omitted from this review. Germanium and silicon are the elements of major importance in this respect and the exceptionally high degree of refinement necessary to make them suitable for semiconductor devices ranks them as the purest materials in industrial use to-day. The desired purity is achieved by a zone refining technique, followed by remelting and the slow pulling of a single crystal by rotating a seed crystal in the melt and steadily withdrawing it. The addition of controlled amounts of known impurities produces specific imperfections in the crystal lattice which give the desired semiconductor characteristics. Germanium and silicon are both Group IV elements to which the addition of such Group V elements as phosphorus, arsenic and antimony creates an excess of electrons for conduction purposes in what is then known as *n*-type material. Group III impurities similarly produce a deficiency of electrons, and gallium, indium and aluminium are used in this way to make *p*-type material in which conduction is primarily by the movement of the so-called positive holes.

The junction of *p*-type and *n*-type materials provides an electrical barrier at which rectification takes place. If another barrier is created very close to the first the resulting *n-p-n* or *p-n-p* combination has the amplifying properties of the transistor. There are limits to the power which can be handled by germanium and silicon and to the frequency and temperature at which they can be operated. A search has, therefore, been made for artificial semiconducting compounds of Group II, III, V and VI elements, and certain useful combinations such as indium antimonide, gallium arsenide, bismuth telluride and cadmium selenide have been developed. The more complex ternary compounds are also yielding useful results.

In the fabrication of semiconductor devices, the chosen single crystal material is cut, sliced, lapped and etched to make the often tiny wafers required and the junctions needed to produce rectifying or amplifying characteristics are then

Fig. 6—120 MW, 13·8 kV, 3000 r.p.m. hydrogen-cooled turbo-alternator for Northfleet Power Station; wound stator



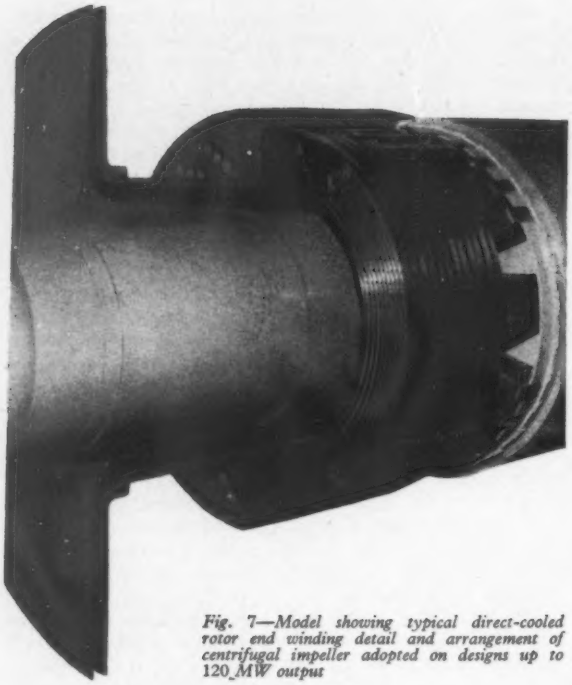


Fig. 7—Model showing typical direct-cooled rotor end winding detail and arrangement of centrifugal impeller adopted on designs up to 120 MW output

frequently made by an alloying process in which, for example, a bead of indium is fused on to the germanium surface and the barrier junction develops in the recrystallized layer at the interface when the molten bead has cooled. The subsequent assembly of the device in an hermetically sealed container (itself often made from copper) requires the use of various non-ferrous metals for the mounting framework and the leads through a vacuum-tight glass-to-metal seal.

Other uses of semiconductor materials under development concern refrigeration and power generation. Certain artificial semiconductors, of which bismuth telluride is conspicuously successful, combine a high electrical conductivity, a low thermal conductivity and a large Peltier coefficient. Temperature differences as great as 85°C. can be obtained at the junction of these by the passage of direct current in the appropriate direction, and by reversing the process, and heating the junction, electric power can be produced. Practical thermoelectric cooling units are under development and power generating units have also been made.

The electrical resistivity of semiconductors, together with other characteristic properties, is affected by light, heat and the magnetic field. There is no doubt that the startling contributions which have already been made by semiconductor devices in the electronic field will be followed by many other significant developments in the future, including some in quite unexpected directions.

Communications

Significant changes are occurring in the materials used in telecommunications systems. Although nickel-iron alloys are still used for loading coils they are being gradually replaced by the non-metallic ferrites, or spinels, which have high permeability and resistivity and are more efficient as inductances. Ferrites have a characteristic square hysteresis loop and for this reason are used for memory stores in computers and similar equipment, as well as for magnetic amplifiers. They are more effective than nickel as magnetostrictive devices in transducers because of a high intrinsic resistivity which reduces eddy current losses. In spite of the growing use of ferrites there may well be a return to the use of 80:20 nickel-iron in the form of thin vaporized magnetic films. These have a high speed of response to signals and are therefore particularly suitable for memory stores in electronic exchanges and computers. Such equipment may also use nickel-iron and cobalt-iron-vanadium alloys for magnetostrictive delay lines. In electronic exchanges, however, there is still scope for the development of new alloys with sufficiently rapid times of response.

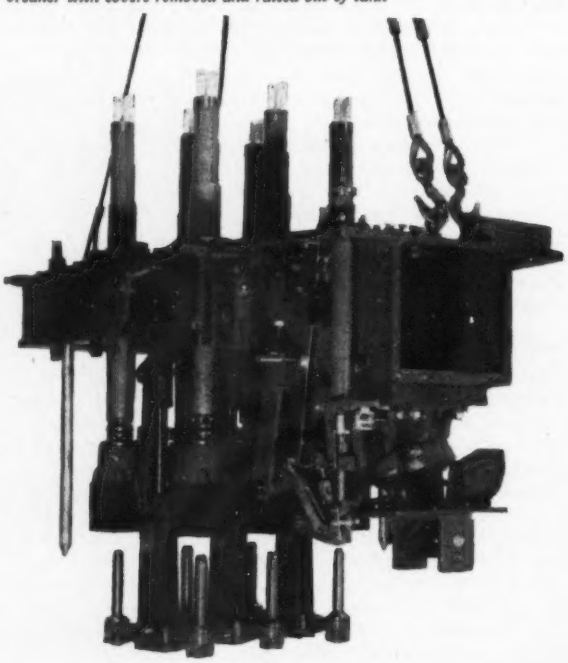
In certain ancillary equipment used throughout the telecommunications and electronics industry progressive improvements have taken place. High purity aluminium foil has proved advantageous in the manufacture of capacitors. Tantalum is also being increasingly used either with a liquid or solid electrolyte, and both niobium and titanium have been employed, but with incomplete success. Nickel-iron alloys have long been used in high frequency transformers and chokes, because of their high permeability, high saturation flux density and high Curie temperature. These alloys have recently been manufactured by powder metallurgy in the form of a very thin strip with remarkably uniform properties and physical dimensions, enabling miniature magnetic cores of high efficiency to be fabricated.

Mention should be made of the extensive use of non-ferrous metals as contact materials in relays and contactors. Platinum and its alloys have long been used for light duty types, and silver and its alloys for heavier duty. In high current density types tungsten or its "heavy alloy" with nickel and copper have been found to be appropriate. Nor should it be forgotten that batteries, both of primary and secondary types, have always found extensive uses throughout the electrical industry and continue to do so, with zinc, manganese, lead and nickel as major constituents in their manufacture. Throughout the telecommunications industry die-castings of aluminium and zinc-based alloys are used extensively, particularly in the production of small, precision components for telephone exchanges, radio equipment and, in fact, electronic apparatus of all kinds.

Power Generation and Distribution

The story of turbines and generators is very largely one

Fig. 8—22 kV type KDS6/1 switchboard for Bermuda: view of oil circuit breaker with covers removed and raised out of tank



of iron and steel. On the alternator side, however, copper will continue to be the conductor whenever it is economically worthwhile, fabricated into forms permitting direct hydrogen- or water-cooling of the tubular windings. Silver-bearing coppers of higher recrystallizing temperature have become important in permitting higher winding operating temperatures. The distribution of the electricity generated has always depended upon copper and, to a lesser extent, aluminium, the use of which is likely to increase if the relative economic situation favours it. Welded aluminium is already being used extensively in place of lead for the sheathing of power and telephone cables. Mercury arc rectifiers and selenium rectifiers have long been in use and will continue so, although semiconductor devices are beginning to invade this field. Fairly extensive use of precision die-casting is made throughout this section of the industry.

Nuclear Power Generation

Probably the most exciting of all developments in the electrical industry in recent years has been the growth of nuclear power generation projects with their promise of making a significant contribution to the solution of the growing problem of providing adequate generating capacity for ever-increasing consumer needs. The years 1947 to 1957 saw an increase in installed capacity of generating plant in England and Wales of 107 per cent. The planned increase for the next five years is a further 44 per cent, of which nuclear power stations will provide some 15 per cent. By 1965, some 12 or more such stations will probably provide at least 6,000 megawatts of electricity and by 1975 the total capacity of nuclear power stations in commission may well exceed the 15,000 megawatts envisaged when the original plans were set out in the 1955 White Paper. From the pioneer station built at Calder Hall by the Atomic Energy Authority to the larger stations now in well-advancing stages of construction by the various Consortia many advances in design, output and efficiency can be seen. The projects are indeed vast, and non-ferrous metals necessarily play a large and important part in their realization, but many of their uses are conventional. The interesting new features have been associated with the nuclear reactor itself, the fissile fuel elements contained in it, the materials used for "canning" the fuel elements and the metals used in the control rods which moderate the nuclear reaction and safely shut the station down in an emergency. In some designs, the heat transfer medium which conveys the heat energy generated in the reactor itself to the, perhaps, conventional steam-raising unit associated with the turbines and generators themselves is also a non-ferrous metal. The new and interesting features not only concern the employment of metals hitherto rarely used in the electrical industry but also the conditions of their use, under neutron bombardment and frequently in a corrosive atmosphere. Developments take place with a speed such that data on the performance of the materials under irradiation are meagre and it is necessary to extrapolate results to predict behaviour during the life of the reactor, usually planned to be of the order of 20 years.

The nuclear fuel commonly employed is natural uranium containing less than 1 per cent of the fissile isotope U_{235}, but enriched uranium and thorium are also under consideration and are the subjects of experiment. In the nuclear reactor the fuel undergoes changes apart from those produced by fission processes. Changes in dimensions occur, due to anisotropic expansion, irradiation causes creep, and volume expansion takes place by the internal accumulation of fission by-products and the occurrence of phase changes at elevated temperatures. These not only make difficulties in securing the satisfactory performance of the fuel element itself, but also impose severe stresses on the can used to contain it. The solution of these problems may lie in the use of alloys of uranium or the substitution of oxides or carbides of uranium or thorium for the metal itself.

The fuel-element "can" must protect the fuel from reaction with the coolant and stop the escape of fission products from the fuel into the reactor, as well as provide an adequately extended surface for heat transfer. Aluminium was employed in the earliest reactors but magnesium alloys are now commonly used. They have temperature limitations, but higher temperatures and specific ratings are possible with zirconium and beryllium, both of which possess adequately low neutron absorption characteristics. Zirconium and its alloys are very expensive, susceptible to corrosion in carbon dioxide coolant gas, and likely to be used only in such structural parts as supports in the fuel-element sleeves. Beryllium is attractive, but the full use of the higher operating temperatures which it makes possible depends upon developments in the fuel itself.

By contrast with the requirements of low neutron absorption in the canning material, the control rod elements must absorb neutrons strongly to be effective. Cadmium is an obvious choice and has been used extensively in research and experimental reactors but some practical designs use boron-steel, or boron in steel tubes, rather than cadmium metal itself.

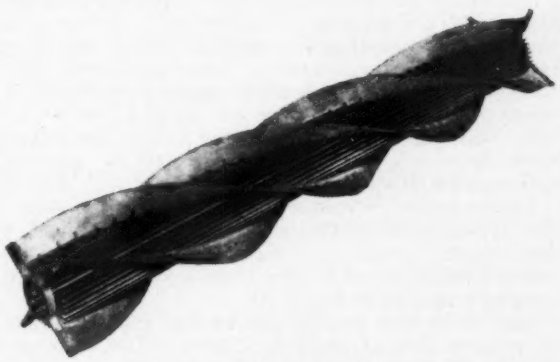


Fig. 9—Fuel cartridge for the Hunterston Nuclear generating station being built by The General Electric Co. Ltd. for the South of Scotland Electricity Board, showing the longitudinal finned can with swirlers, both made from Magnox A 12 alloy.

In some cases, liquid metals have been proposed for the coolant and heat transfer medium. Mercury was considered, but not used on account of its high neutron absorption. Sodium has been used in graphite moderator reactors, but suffers severe corrosion. Liquid metal coolants are, however, feasible in fast reactor systems, where the neutrons emitted in the fission process are not subject to slowing down by moderator material. Sodium has good heat extracting properties for this purpose but is impracticable from reaction and radiation considerations. Potassium has not been used other than in the form of the sodium-potassium eutectic which, although less efficient as a coolant, has the desirable property of remaining liquid down to 20°C. An experimental system (U.S.A.) has used enriched uranium metal dissolved in molten bismuth for circulation in the dual role of fuel and coolant.

It will be clear that atomic energy developments provide many specialized problems in the non-ferrous field leading to new criteria of purity, reliability and performance. The standards required are possibly more severe than in any other branch of the electrical industry, apart from the semiconductor field, where the possibilities associated with failure of the materials do not carry the catastrophic risks inherent in reactor systems. Much remains to be done before the long term satisfactory behaviour of the metals, particularly under irradiation, can be assessed and assured.

1909 - 1959

NON-FERROUS METALS

their Military Application

by L. J. BRICE, M.Sc., F.I.M.

Armament Research and Development Establishment Fort Halstead

IN the Boer War of 1899-1902, each rifleman carried a brass butt-plate on his rifle, a brass weight for his cleaning pull-through and brass oil bottle. He also had his quota of ·303 in. ammunition, consisting of solid drawn brass cases and lead-antimony bullets with their cupronickel envelopes introduced to reduce fouling. Cavalrymen used swords with brass guards, drawn from scabbards with brass mountings.

The Maxim machine gun, successor to the hand-operated Gatling, ·45 in. Gardner or ·303 in. Nordenfelt machine guns, which used a considerable number of cast bronze components, was fitted with a copper-plated steel barrel, brass water jacket, cast brass or bronze control handles and other minor fittings (see Fig. 1). It was fed with ammunition belts consisting of lengths of webbing divided into pockets by brass strips. The 1 pr. pom-pom was an up-scaled version of the Maxim.

Large quantities of brass were used for small arms ammunition cases, but for gun ammunition cases the consumption was relatively small, since most guns then were of the breech-loading type using bag charges, such as the most commonly used 15 pr. and 12 pr.

Fuze bodies were made in gunmetal—87 per cent copper, 3·5 per cent tin, 6 per cent zinc, 3·5 per cent lead or (drawn) 90 per cent copper, 7 per cent tin, 3 per cent zinc. Manganese bronze was used for base fuzes and 60/40 leaded brass for fuze rings.

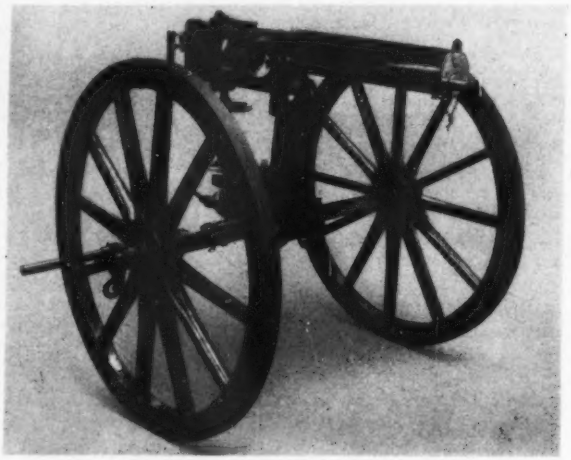
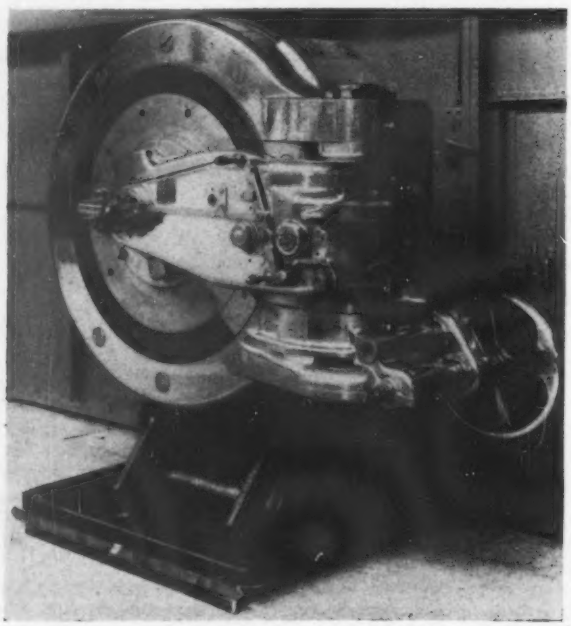


Fig. 1—0·45 in. Maxim machine gun.

Fig. 2—Breech of Breech Loading 12 in. Mk XII gun



For shrapnel shell, lead-20 per cent antimony (later 12·5 per cent antimony) alloy was used for the bullets, of which the numbers per shell ranged from 42 in the 7 pr. (3 in.) R.M.L., to 638 in the 9·2 in. B.L. Zinc was used for cartridge cylinders.

Non-ferrous metals, mainly copper and its alloys, also found their way into many miscellaneous applications such as harness fittings and accoutrements, R.E. equipment, railway equipment, telegraph and telephone lines and cable. There were important requirements, too, for bearings, drag hooks, locks, hubs for limbers, G.S. wagons; lighting and heating equipment for barracks and stores, kitchen utensils; tinned copper camel tanks, forerunner of the jerrican.

In view of the importance now attached to control of composition, properties and quality of alloys used for the Services, it is interesting to note the following, taken from Service specifications approved in 1900:

Cartridges, S.A., Ball, ·303 in. Mk. V.

Case: copper 65-70 parts, spelter 35-30 parts, lead <0·3 per cent, total metallic impurities <1 per cent.
Bullet core: lead 98 parts, antimony 2 parts.
Bullet envelope: copper about 80 per cent, nickel about 20 per cent, iron about 0·5 per cent.

Gun, Maxim, ·303 in.

Gunmetal: "To be hard and tough and free from honeycomb or other defects. Copper about 87 parts, tin about 11·6 parts, zinc about 1 part. Breaking strain >15 tons/in^2, elongation >11 per cent".

Reading the above, modern manufacturers, harassed by

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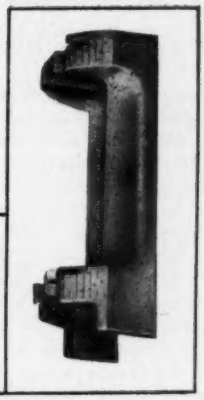

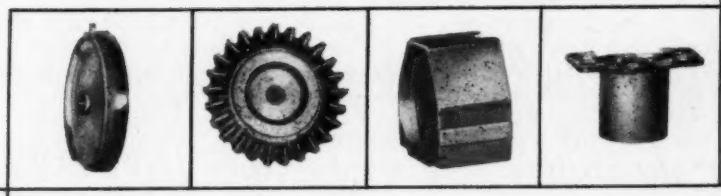

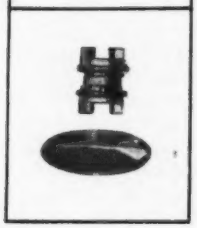

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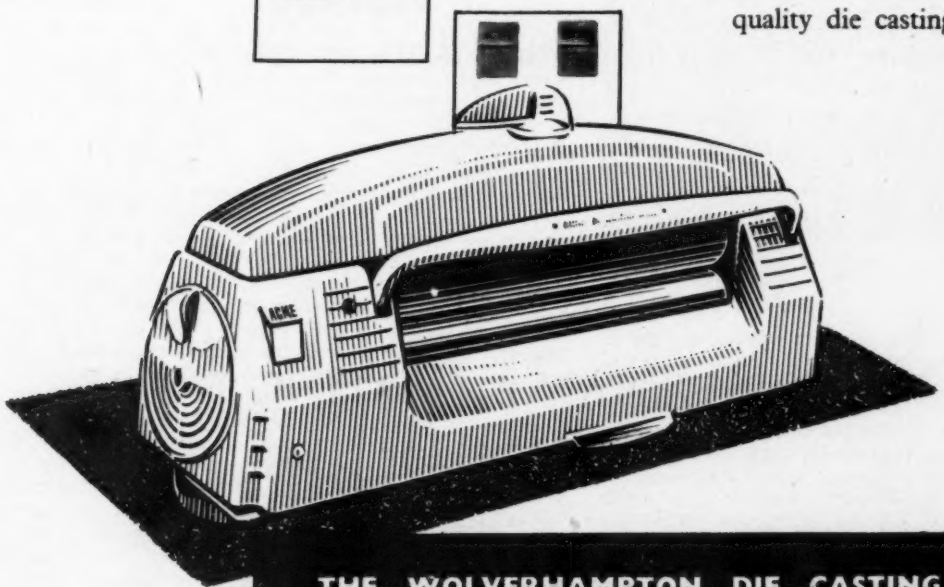

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vigilant inspectors will sigh for those tolerant days, when compositions were no closer than "about", although argument must have run high at times on the interpretation of "about". It is reassuring to learn from the Royal Commission's report on the war that "gun ammunition was of good quality and excelled that of the Boers, whose shells, owing to defective fuzes, frequently did not burst".

On the other hand, there appears to have been some public outcry over faulty ammunition. As a result of the recommendation of a Government committee of enquiry, which included several eminent scientists, a Chemical Research Department was established at Woolwich Arsenal in 1903. Metallurgical research on specifically Service problems commenced in 1904 with the appointment of a chief metallurgist.

WORLD WAR I

One of the most important new factors introduced in this war was the scale of operations and the consequent problems of supply and production. In a little over four years, more than 196,000,000 rounds of gun ammunition of *all* types were filled and completed in the U.K. and another 21,000,000 by Canada and U.S.A. for the British Forces. During the Autumn campaign of 1918, an output of 21,143,000 rounds in three months was achieved in the U.K.

The Non-Ferrous Metals Department of the Ministry of Munitions very quickly became immersed in vital questions of sources of supply of raw materials and transportation routes, price control, control of distribution to ensure the cutting-off of all possible supplies to the enemy and to non-essential industry, and the use of substitutes to meet shortages. A Metals and Materials Economy Committee considered possible savings and substitutions.

Shell driving bands absorbed a large tonnage of pure copper, output increasing from 80,000 rings per week from two firms in 1914 to 1,350,000 per week from 114 firms later.

Owing to prior claims on copper tubing by the Admiralty, and shortage of tube-making facilities, alternative methods of production to the cutting of specified lengths from tubes were introduced. The total production for all sizes was: from tubes—91 m., brazed strip—4¼ m., cast—¼ m., butt-jointed—28½ m., from pressed cups—49¼ m.; total—173¼ m. approximately. The substitution of lighter bands for certain shell saved 19,000 tons of copper per annum.

Large amounts of copper also went into 70/30 brass for gaines, primers, vent sealing tubes and cartridge cases. By the end of 1917, the trade was producing 2,000 tons of strip per week and the special Government mill at Southampton about 400-450 tons per week.

60/40 brass, using 99·25-99·5 per cent zinc, was used for fuze bodies. To relieve pressure on rolling mill capacity, considerable use was made of hot stamping of billets from cast brass containing high proportions of scrap. By 1917, 1,750,000 stampings per week were being produced. Lead-free brass was specified in certain cases, to prevent formation of sensitive salts when contact with picric acid was unavoidable.

On certain guns, the breech carrier and carrier ring were of cast brass or bronze, the largest being those for the B.L. 12 in. Mk. XII, shown in Fig. 2, the carrier ring of which weighed 3½ cwt. Hand wheels, levers and rods on carriages were also mainly of cast brass or bronze. Other important applications of these alloys included castings for the Vickers machine gun mounting; barrel and framework of signal pistols; bearing strips and bushes, brackets and housings; humane killers, miscellaneous items on web equipment (introduced in 1908).

In the interests of economy, there was special control of swarf and scrap, especially in view of the large quantities (up to 50 per cent) produced in ammunition manufacture. Up to 75 per cent of fired cases were returned for repair, brass was replaced by cast iron for certain fuze bodies, nose bushes of H.E. shell, cups for certain shrapnel shell; and by steel for central tubes of shrapnel shell, primers and 4·7 in. cartridge cases.

The shortage of zinc was very acute in the early part of the war. Problems of supplies included shortage of smelting capacity, loss of German spelter (which had absorbed the bulk of the Australian output of zinc concentrates) and production of 99·9 per cent "fine zinc" for cartridge case manufacture. At one period, the need for economy stimulated trials with 85/15 brass for cartridge case production. The Australian output was, however, secured, the Fricker process for refining spelter in the U.K. was successful and Norway, Canada and U.S.A. helped with "fine zinc" supplies. Up to 30th April, 1919, the Non-Ferrous Metals Department of the Ministry of Munitions dealt with 181,336 tons G.O.B. spelter and 90,067 tons refined zinc.

The main applications of tin in munitions production were for tinplate, solder, gunmetal, bearing metal, "plastic metal" for repairing bearings (containing tin 75 per cent, copper

Fig. 3—Aluminium eagle for Napoleonic regimental standard. (Courtesy Aluminium Development Association)

10 per cent, antimony 12 per cent, lead 3 per cent), shell linings, 60/40 tin-lead foil for decoppering guns, 80/20 tin-zinc for cartridge lids (later specified to be free of aluminium, which was found to cause embrittlement on ageing).

Antimony was used for lead alloy bullets for shrapnel shell and small arms ammunition and for case shot fillings.

Large quantities of nickel were consumed for cupro-nickel sheet for bullet envelopes, the trade producing 500 tons per week in 1917 and the Government Southampton mill, 60 tons per week.

Aluminium came into prominence for alloy fuze bodies, hand grenades, small arms ammunition bullet tips, incendiary bombs, finned radiator casings for the Lewis gun, motor transport, explosives and smoke compositions in H.E. shell and even water bottles and mess tins. In 1917, consumption was 21,440 tons, covering Admiralty (2,000 tons), Air Dept. of the War Office (5,000 tons) and the main Army uses: smoke mixture (3,136 tons), motor transport (2,250 tons),

Left: Fig. 4—Die-cast percussion fuze in zinc

Below: Fig. 5—Bofors gun foresight die-cast in zinc alloy

Table I—Military Specifications for Non-Ferrous Metals

Material	Tenacity tons/in² (min.)		Elongation % (min.)
	Yield	Breaking	
Class "A" metal	20	30	20
Aluminium Bronze	20	42	18
Class "C" metal (from finished bar, casting, or stamping)	6	12	10
Class "G" metal (from finished bar, casting, or stamping)	8	20	12
Aluminium Alloy (from finished bar, casting, or stamping)	7·75	12	7
Class "B" metal (from finished bar)	12	20	30
Class "D" metal (from finished bar)	16	24	20
Class "E" metal (from finished bar)	9	16	30
Phosphor Bronze (from finished bar)	20	30	20
Manganese Bronze (from finished bar)	18	34	20
Special Manganese Bronze (from finished bar)	13·5	27	20
Hard rolled brass (from finished bar)	6	12	10
"A" Bronze	—	28	15

Metals designated by "Class" were to be copper alloys.

fuzes (2,220 tons), high explosives (1,660 tons), machine guns (1,066 tons) and ammunition, hand grenades, tanks, explosives works, bombs and shell (up to 500 tons each). The consumption was reduced by one-third in 1918.

With progress of the war, economy in military applications of aluminium became necessary and there was close control of both metal and scrap. Thus in November, 1915, brass was substituted for the No. 80 fuze body. Granulated metal was made from scrap and swarf for thermit reactions, re-melted scrap was used for motor vehicle parts. Granulated aluminium used in the high explosive, ammonal, was reduced from 17 per cent to 6-10 per cent and eventually eliminated when amatol was introduced. The order of priorities was in fact: Air Depts. of the Admiralty and War Office, machine guns, steel making, motor transport, fuzes.

Towards the end of the war, the U.K. became self-supporting in regard to aluminium. Supplies improved so much, in fact, that replacement of brass components by aluminium alloys was considered.

Specifications

The specifying of non-ferrous metals was still very unsatisfactory compared with modern procedure. Drawings from the Superintendent of Design were marked, where appropriate, "Steel" or "Metal". It was for the Inspectorate to draw up store specifications and choose an appropriate metal specification or "class" of metal.

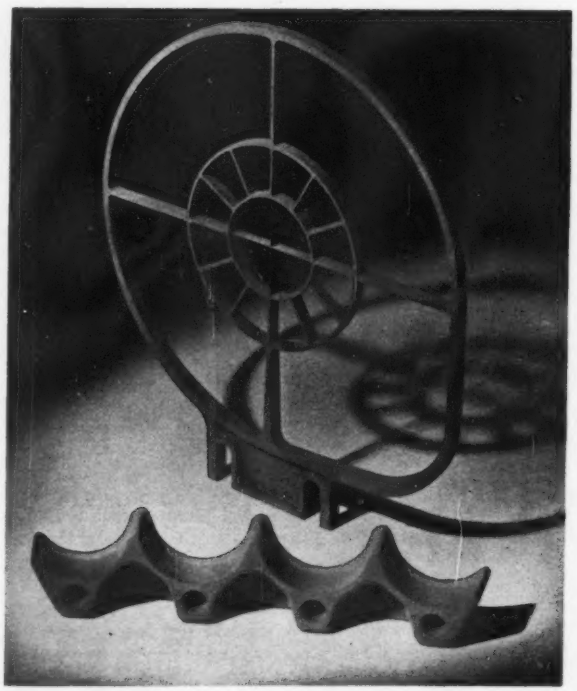
In general, compositions were left to the manufacturers' discretion, provided that any lead content specified in the Contract was not exceeded, that "aluminium alloy" contained not more than 10 per cent zinc and 1 per cent iron, and that the mechanical tests detailed in Table I were met.

For cartridge brass, copper was still 65-70 per cent, but impurities much more closely defined and limited to: nickel 0·2, iron 0·15, lead 0·1, arsenic 0·05, cadmium 0·05, bismuth 0·006, per cent maximum, antimony nil, tin nil.

During the war, the scientific treatment of Service metallurgical problems and helpful advisory relations with design, production and inspection departments, and industry, which have continued so successfully ever since, were well established. Specific investigations in the Research Department covered the design and manufacture of bullet envelopes, failure of fuze components, the extrusion defect, and the behaviour *v.* properties (especially Brinell hardness) of small arms ammunition. Other activities were concerned with substitute materials, alternative methods of manufacture, specifications and concessions, inspection tests, examination of enemy material, and of failures in service.

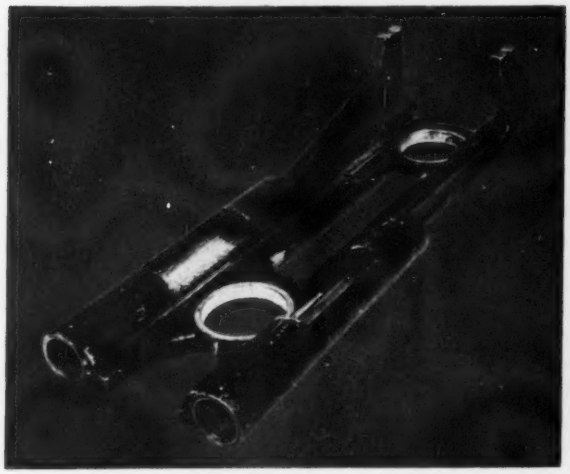
WORLD WAR II

Once again, the scale of operations necessitated a policy of stringent conservation, by reduction of consumption, conserving the maximum quantities of material likely to be in short supply, substitution, salvage, exploration and development of new idigenous sources of materials and increased exploitation of existing sources. The Non-Ferrous Metals Control was set up immediately on the outbreak of hostilities to implement this policy as well as to secure adequate imports.

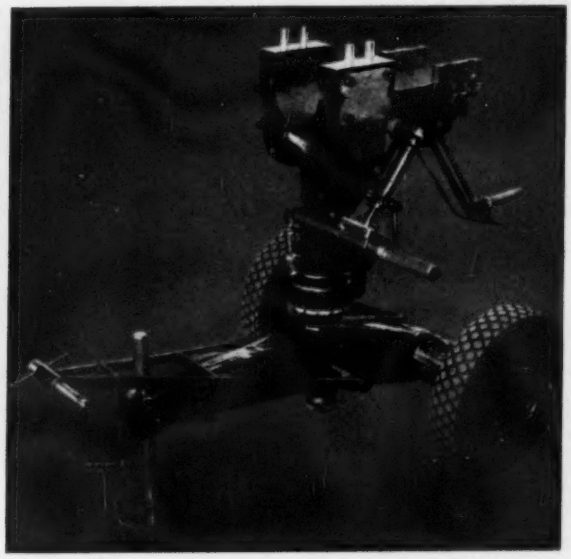


Copper, zinc and lead came under statutory regulation at once; tin, nickel, cadmium in December, 1941, following Pearl Harbour; antimony, in January, 1942; cobalt, in May, 1942; manganese under "supervision" from December, 1941.

Copper was, of course, again in great demand for brass cartridge cases, shell bands, and fuzes. Attempts to replace brass by aluminium or steel for cartridge cases did not reach production stage. A small, but highly important, requirement was for phosphor bronze for A.A. mechanical fuze hairsprings. Vehicle components included tinned copper radiator labyrinths, bronze bearings, gear selector forks, etc. For guns and carriages, consumption was nearly 2,250 tons alloys p.a.—20 per cent rods, bars and section (75 per cent manganese brass, 25 per cent phosphor bronze) and 80 per cent castings. For the 3·7 in. A.A. Mobile Mounting Cradle a 1,250 lb. casting in STA. 7/CM.6A (57-63 per cent copper, 0·5 per cent maximum tin, 1 per cent maximum lead,



Above: Fig. 6—Sand-cast aluminium alloy gun cradle



Right: Fig. 7—Cast magnesium alloy gun mounting

0·5-1 per cent iron, 2 per cent maximum manganese, 0·5-2 per cent aluminium) was used, whilst the 40 mm. L/60 Light A.A. gun had a base and side frame casting in CG.3 (88/8/4 gunmetal). Another important requirement of copper was for communications, instruments and electrical equipment. Aluminium bronze, phosphor bronze, and beryllium copper were used for tools for use with high explosives.

Although consumption rose from 258,000 tons in 1938 to a peak of 490,800 tons in 1942, the maintaining of adequate supplies (from Canada, Rhodesia, South Africa, Congo and U.S.A.) remained acute throughout, even with economies such as development of the use of steel, clad with cupronickel or gilding metal, for bullet envelopes, replacement of brass fuze components by zinc base die-castings, of equipment (buttons, badges) by steel, and gun mounting castings by meehanite.

In peak quarters, the rate of output of brass and other copper alloy sheet and strip was 470,000 tons per annum. Industry increased output fourfold.

To overcome bottlenecks in the production of extruded and rolled bar, cast bars were used for stampings: and at one period, to increase production, gravity die-cast aluminium bronze (11 per cent aluminium, 3 per cent nickel) replaced steel for Sten gun breech blocks. The use of lead-bearing brasses greatly increased production by reduction of machining times for components.

Apart from essential requirements such as brass, die-castings, strip and sheet for battery cans, oxide and dust for smoke mixtures, the use of zinc had to be severely limited, especially from 1941. Considerable economies resulted from excluding normal galvanizing except for a few special Admiralty requirements, reducing thickness of coatings as on wire and wire rope, and using alternative protective coatings such as Bonderizing, Parkerizing and Brunofix. After 1941, zinc milk bottle caps were replaced by 92/8 tin/zinc and then aluminium.

Supplies of lead were needed mainly for cable sheathing, batteries, for fighting vehicles, etc., bullet rod and shrapnel, solders, 40/60 lead/tin decoppering foil, 4·5 per cent tin/<1 per cent antimony foil for detonator caps, lead/3 per cent tin tubing for "Fuze, Instantaneous, Detonating" ("Cordeau Detonant"). Fine grain copper or copper-tellurium chemical lead was introduced for improved resistance to vibration or thermal expansion and contraction. New cable sheathing alloys with increased resistance to fatigue contained 0·8-0·9 per cent antimony or 0·4 per cent tin/0·15 per cent cadmium or 0·4 per cent tin/0·2 per cent antimony. A considerable tonnage of the latter alloy was used for "Pluto". With severe restrictions on use of lead sheet and pipe for buildings, the supply position was satisfactory and, in fact, lead was used at times to replace scarcer materials, e.g., white lead replaced zinc oxide for paints.

A serious situation arose after the loss of Malaya and Dutch East Indies, which involved the cutting off of over 60 per cent tin supplies available to the Allies. Consumption had quickly to be reduced by about 50 per cent. Consumption for tinplate was reduced to 30 per cent by replacing, for example, tinplate drums for oil and food containers by blackplate or by other protective coatings and by use of terneplate. In the alloy field, the use in solder was cut by 50 per cent by the use of economy soft solders (B.S. 219:1942) and in bronzes by a considerable amount, by the use of B.S. "War Emergency" compositions, such as the 86/7/5/2 or 85/5/5/5 Cu/Sn/Zn/Pb alloys.

Greater use was made of lead-base bearing metals. At one period tin-lead decoppering foil was replaced by lead foil (4-5 per cent tin +1 per cent antimony or up to 4 per cent "other elements").

In 1942, consumption (85 per cent for Government) was about 14,000 tons for alloys, 8,000 tons for solder, 5,500 tons

for tinplate, the balance for foil and collapsible tubes, tinned-copper wire, compounds and salts, tinning, etc. About 30 per cent of this consumption was in the form of scrap.

In 1942 and 1943, there was a danger of inadequate supplies of nickel, and consumption was reduced from 22,500 to 17,200 tons per annum by restricted uses (e.g., cupro-nickel replaced by gilding metal, or gilding metal-coated steel for bullet envelopes) and war emergency compositions, as for alloy steels, which accounted for 75 per cent consumption. Towards the end of 1944 the position was greatly eased.

The principal "non-ferrous" uses were for cupro-nickel; nickel silver (14-16 per cent nickel or 9-11 per cent nickel) for instruments, surgical instruments, electrical apparatus, badges, cutlery and flat ware; Monel metal for fuze inertia pellets, searchlight electrode holders, tools for use with explosives; and aluminium alloys. Also, over 500 tons per annum of nickel anodes were used, especially for building up worn or over-machined parts by electrodeposition.

Earlier, separate controls for aluminium, light alloys and magnesium were taken over by the Light Metals Control in July, 1941.

The bulk of Service releases of aluminium was for aircraft construction. There were, however, very limited non-aircraft applications. In these, castings and wrought metal had to have a minimum of 25 per cent and 75 per cent virgin metal respectively, except when wholly secondary casting alloys, D.T.D. 424 and 428 and a key alloy D.T.D. 479 for reclaimed metal were specified. Relatively small quantities went into tank engine castings, lighting and gun control systems, military transport, bridging and pontoons. Tank periscope prism mountings had to shatter on being hit and were of a special alloy containing 17-21 per cent copper, <4 per cent silicon, 2-6 per cent zinc, 0·14-0·20 per cent titanium. Time fuze caps were gravity die-cast in aluminium-silicon, L.33, 40 mm. ammunition charges die-cast in D.T.D. 424 and 40 mm. A.A. fuze bodies machined from Duralumin bar and anodized. Other applications included V.T. fuze forgings, magazine covers, bomb tail units, radio equipment, mess tins and containers. Pre-war trends to introduce aluminium for kitchen and field cooking utensils, hollow ware, barrack and hospital stores, had to be stopped. With cuts in the aircraft programme from mid-1944, substantial quantities of aluminium became available for non-aircraft purposes.

There had been abortive experiments before the war with magnesium artillery wheels and up to July 1940, certain vehicle components were permitted in magnesium alloy. Thereafter, however, the whole of the virgin and secondary magnesium available was used for incendiary bomb castings (52·5 per cent)—over 91 million 4 lb. Mk. I bodies of 3·5-5 per cent aluminium alloy were produced 1939/45—aircraft castings (22 per cent), powder pyrotechnics—as for star shells, flares, photo flashes, etc.—(8·3 per cent) and, in relatively small amounts, for sheet, strip, extrusions and forgings for aircraft. The army was virtually excluded from participation.

Miscellaneous Applications

Although ammunition in particular accounted for such large consumption of the base metals, other important applications of a variety of non-ferrous metals must not be overlooked. These include gunfire control equipment, optical instruments, electrical testing and measuring instruments, infra-red and ciné equipment, transformer windings, fractional horse-power motors, magneto slips, platinum for contacts, relay leaf springs, control springs, and thermionic valves.

Cobalt was used as a binder (10-13 per cent) in tungsten carbide armour piercing cores, and in permanent magnets. Significant quantities of zinc, cadmium, tin and lead were used as protective coatings against corrosion, but consideration of this group of applications has been deliberately omitted from this article.

Fig. 8—Aluminium alloy liquid fuel container for portable flame-thrower

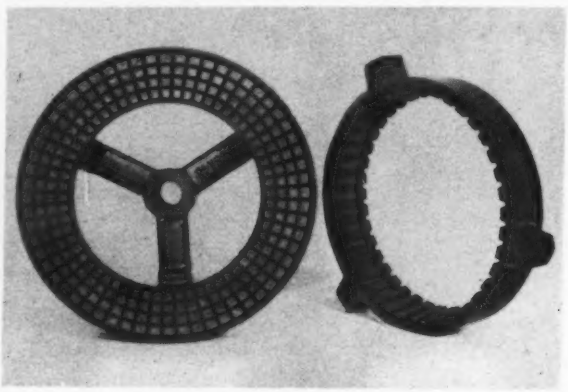


Fig. 9—Die-casting: Left, valve from petrol pump in silicon brass. Right, Fighting vehicle gearbox component in aluminium bronze.

Die-Casting

The use of this production technique for Service components was a vital factor in maintaining high rate of output, economizing in metal and in man-hours (through simplicity of operation and elimination of most machining operations). Mazak 3, based on high purity (99·99 per cent+) zinc and very low impurity contents, introduced before the war, was used in very large quantities. In the peak year, 1942, about 50,000 tons of zinc were used. On occasion the average weekly output was 12,000,000 ammunition die-castings, mainly fuze components, mortar bomb tails, grenade centre pieces and bodies, plugs, shell caps, nose adaptors. A large proportion of these had cast threads. The Q.F. 40 mm. A.A. gun equipment also included die-castings for the sight, telescope cradle, range drum: the 17 pr. A/T guns also had die-cast range drums and telescopic cradles.

Earlier embrittlement troubles arising from excess of impurities (especially lead, tin, cadmium) were largely overcome by the issue in December 1941 of B.S. 1003 and 1004. The necessary high quality of Service castings was further maintained by the activities of the Advisory Committee (Die Casting) set up in August 1941, and consisting

of Service and industrial representatives. This body issued a unique specification controlling manufacture and inspection of zinc alloy die-castings, and a background booklet. It also classified die-casting firms, set up facilities for extensive X-ray examination of castings and spectrographic analysis and, through its industrial members, gave expert advice on design and production technique.

Compared with zinc alloy die-castings, the production of aluminium alloy die-castings for non-aircraft purposes was severely restricted. However, useful quantities of fuze caps, ammunition chargers, bomb tail units, etc., were produced.

Specifications

Before World War II, a number of Service departments issued their own metal specifications, in certain cases a firm's own internal specification was used, and chemical compositions were often only loosely specified, or not at all, as in the "Class" and other metals listed in Table I. This situation complicated ordering, supply and inspection, and many manufacturing difficulties arose through wide variations in compositions supplied to the same "specification".

Under a new, largely advisory, department in the Ministry of Supply—Superintendent of Technical Applications of Metals, set up during the War—the very important task of co-ordinating and rationalizing metals specifications was undertaken, in full co-operation with Service departments, the British Standards Institution and industry. The result was the issue and widespread use of B.S./STA. 7, "Services Schedule of Non-Ferrous Metals and Alloys".

In addition to a section on "Conditions of Supply", there was a section for each metal group in which the individual metals and alloys were specified by composition and wherever appropriate by mechanical properties, each having a separate designation, which could be quoted on drawings. The highly unsatisfactory situation existing previously was thus largely rectified. A notable achievement was the specifying for the first time of compositions for high tensile brasses, which considerably eased machining problems. Generally, compositions were identical with or similar to B.S. Specifications, although special purpose alloys were included, such as the base fuze alloy, nominally copper 57 per cent, zinc 37 per cent, manganese 2 per cent, iron 1 per cent, aluminium 3 per cent, and the die-casting alloy for the Sten gun breech block, nominally aluminium 11 per cent, iron 3 per cent, nickel 3 per cent, copper remainder.

Separate S.T.A. specifications were issued to cover copper rings and strip for driving bands, 95-98 per cent copper/5-2 per cent zinc strip for detonator shells and percussion caps, 70/30 brass strip for cartridge cases and caps, gilding metal strip and gilding metal coated or cupro-nickel coated steel strip for bullet envelopes, terneplate.

A feature that came into special prominence during this war was the behaviour of stores and individual components under tropical and arctic conditions. This involved considerable time and effort in ascertaining properties of materials at low and elevated temperatures, effective protective treatments and packaging.

POST-WAR

The demand for "conventional" armaments and equipment is likely to continue for a long time, though on a more limited scale. Considerable modifications to design to meet modern requirements have in many cases, however, involved changes in materials to be used. A special feature is the need for reducing weight to a minimum, e.g., for airborne equipment, engineering equipment such as bridges, pontoons, etc., gun carriages, mortar barrels and baseplates, discarding sabots for high velocity shell. Thus, light alloys have come into prominence, particularly aluminium alloys and, to a lesser extent, magnesium alloys. For the time being, particularly while relatively costly, titanium alloys have very limited potential Army applications.

A feature of the "post-war" period has been the intensive development of new ranges of weapons—atomic, guided, rockets; for these, the special conditions of operation demand ferrous rather than non-ferrous alloys, although light metals have been considered in certain projects, for example, Duralumin for rocket motor tubes.

Much of the information in this article has been obtained from the following sources:

1. Report of H.M. Commissioners appointed to enquire into the Military Preparations and other Matters connected with the War in South Africa—Cmd. 1789, H.M.S.O.
2. History of the Ministry of Munitions.—H.M.S.O.
3. History of the Second World War.—H.M.S.O.
   (a) Statistical Digest of the War.
   (b) British War Production.
4. Histories of the Non-Ferrous Metals and Light Alloys Controls (unpublished).

In addition, grateful acknowledgment is made to many colleagues in the Ministry of Supply, officers in the Board of Trade and War Office library, members of the staff of the Royal Military College of Science, Dr. H. Moore, C.B.E., former Director of Metallurgical Research, Woolwich Arsenal, The Zinc Alloy Die Casters Association and Mond Nickel Company for information and provision of documents. Figs. 1, 2, 6, 7, 8 and 9 are Crown Copyright reserved, reproduced by permission of the Controller, H.M.S.O.

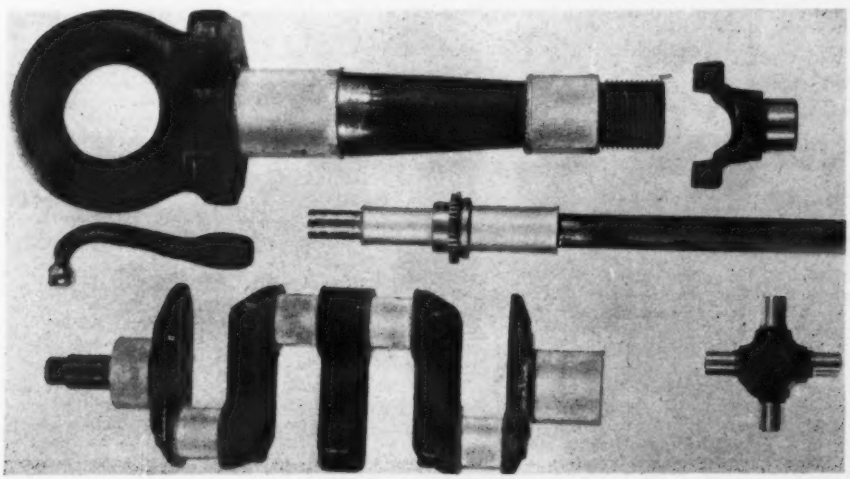


Fig. 10—*Worn components built-up with electrodeposited nickel*

Industrial News

Home and Overseas

An Aluminium Warehouse

Aluminium is the keynote, both in construction and in the goods it will house, of the new building in Clement Street, Birmingham, which has recently been completed for **Aston Aluminium Warehouse Company Ltd.** and which was formally opened on behalf of the company by Mr. H. R. Murray Shaw, director of the Aluminium Industry Council, on Tuesday last.

Since its formation in 1949, in what was formerly a disused bakery at Aston, the company has twice outgrown its available premises, and it was this year found necessary to move once again, and this accommodation in Clement Street provides still more extensive accommodation. Aluminium is used wherever possible in the construction of the new building. The roof, window frames, curtain walling and many other factors are made in light alloy, many of the fittings have been anodized, in some cases in natural and in others dyed.

The spacious well planned warehouse and adjoining departments have all been designed solely for the storage and resale of aluminium. The warehouse is heated by oil in order to maintain an even temperature, and to overcome temperature changes and consequent condensation. The offices occupy two floors and have floor heating thermostatically controlled.

The company supplies aluminium and aluminium alloy "semis" in varying quantities, shapes, sizes, grades and hardness, and it may well be that the company is now one of the largest of its kind in the country. An essential feature of a specialist warehouse is to pay careful attention to probable new outlets for the metal. In recent months there has been a growing interest in the use of aluminium alloys in commercial transport and in the building industry. New designs for lorry bodies calling for special sections in light alloy have become popular. To meet this need the company has set up a separate organization in Alloy Transport Sections Ltd. The purpose of this concern is, first, to meet from stock supplies of special sections, plate and ancillaries for the lorry body builder; secondly to supply a complete broken-down kit, and finally for quick assembly of light alloy bodies on the spot.

Many of the leading personalities in the aluminium industry were present on Tuesday at the opening of the new buildings, and were also able to inspect the warehouse, offices, etc., which will enable the company to provide an increasingly rapid and efficient service to the industry in the Midlands.

Vacuum Metallizing

Evidence of the increasing use of metallized paper and plastics in the packaging and electronic industry is shown by the sale of metallizing plant by **Vacuum Research (Cambridge) Ltd.** Three metallizing plants, each capable of turning out nearly two and a half acres of metallized plastics film or paper per hour, have been exported to the United States. A complete plant has also been recently exported to Sweden.

These large machines deposit aluminium on to a moving web 60 in. wide, travelling at 5 ft/sec. For the electronic industry a new technique has been evolved for the production of metallized film in narrow widths with a metal-free margin for use in capacitors. The master roll is metallized, margined, slit and re-reeled on to narrow spools in a single operation.

Light-Alloy Towers

Radio towers, two in number, have been designed and manufactured by **Saunders-Roe Structures Ltd.** These towers were ordered for a Government Department for erection on a site overseas, the nature of the site being such that a guyed mast could not be used and the base area of the mast had to be of minimum size. Light alloy was selected as being the most suitable material, as it required little maintenance.

The towers, which are of novel design, are each 366 ft. high in the fully extended condition and may be adjusted (during erection) over a range of 16 ft. to suit the final detail electrical characteristics of the transmitting installation. Each side of the triangular base of the tower is only 20 ft. The diameter of each of the tubular legs at the base measures only 7¼ in., graded to 5 in. at the top, and the total weight of a complete tower, excluding insulators, is less than seven tons. Because of their new features, these towers and their components have been subjected to considerable testing. For example, the main joints have been tested to destruction, welded specimens have been similarly treated, and the final components have received control checks.

Shipped to South Africa

Measuring 34 ft. in length, what are described as the longest one-piece non-slip stair treads ever to leave this country have just been shipped to South Africa by **Ferodo Limited.** These stair treads are destined for Witwatersrand University at Johannesburg, where they will be fitted in the main entrance of the mining and geology block.

To keep the stair treads, which are aluminium channel with Ferodo non-slip fabric inserts, perfectly rigid in transit, a special packing case with extra reinforcements was made.

A Brussels Conference

Under the auspices of Cebelcor, l'Association Belge d'Electrodéposition has organized a conference on "Influence Des Formes Sur L'Aspect Des Depots Electrolytiques", by M. Godeaux, to be held on December 17 next at 3 p.m., at Fabrimetal, 21 rue des Drapiers, Brussels.

The conference will be followed by a general debate on all matters relating to electrodeposition. Further information may be obtained from the secretary of Cebelcor, 24 rue des Chevaliers, Brussels, 5.

Pig Iron from Scrap Steel

Although electric arc furnaces used for the production of steel from scrap metal are quite common to-day, the production of pig iron from reclaimed scrap steel is said to be a departure from normal practice.

Ferranti Ltd. have recently installed a new Birlefco 3 ton capacity electric-arc furnace which will now enable them to indulge in this new process. The company believes that they are the first heavy electrical engineering company in this country to put such a scheme into operation.

The new 1,600 kVA furnace, installed in the foundry, consists of a cylindrical refractory-lined, bowl-shaped shell of 7 ft. diameter with three triangularly-spaced electrodes projecting vertically through the removable roof and connected through flexible cables to a furnace transformer. The roof ring in which the roof refractories are seated is water-cooled, as are the electrode arms and clamps in which the 8 in. dia. by 6 ft. long electrodes are held.

A Top Award

Employees of **Holman Brothers Ltd.** are encouraged by what is called the "Suggestogram" scheme to put forward suggestions for improving efficiency, increasing productivity and cutting production costs. Not only does it promote the active interest of employees in the group's manufacturing activities, but there are also generous rewards for any good idea adopted. To quote from the Holman Group Handbook, "the awards usually equal the estimated direct wages saved in one year." A substantial saving in material is also rewarded.

In a recent review by the Suggestogram Committee of the current ideas received, the top award went to a 28-year-old, Mr. William Small, an inspector in the Carn Brea works, who has been presented with a cheque for £580 by the company. His idea has resulted in a new method of lining vats used in an electroplating process which cuts installation and renewal costs appreciably.

Forthcoming Meetings

December 8—Institute of Metals. South Wales Section. Royal Institution, Swansea. Discussion on "The Study of Metallurgy". Contributions by Prof. A. R. E. Singer, Prof. E. S. Sellers, Prof. R. H. Macmillan and M. R. Hopkins. 7 p.m.

December 9 — Non-Destructive Testing Society of Great Britain. Birmingham Branch. Engineering Centre. "Some Aspects of the Economics of N.D.T." W. G. Cook. 7 p.m.

December 9 — Society for Analytical Chemists. Midlands Section. Wolverhampton and Staffs. College of Technology. "The Determination of Trace Impurities in Metals." Discussion. B. Bagshawe, W. T. Elwell. 7 p.m.

Birmingham Metallurgical Society. Joint Meeting with Birmingham Local Section of Institute of Metals. College of Technology, Gosta Green, Birmingham, 4. "Hot Dip Galvanizing." M. L. Hughes. 6.30 p.m.

December 10—East Midlands Metallurgical Society. School of Art, Green Lane, Derby. "Vacuum Metallurgy." 7.30 p.m.

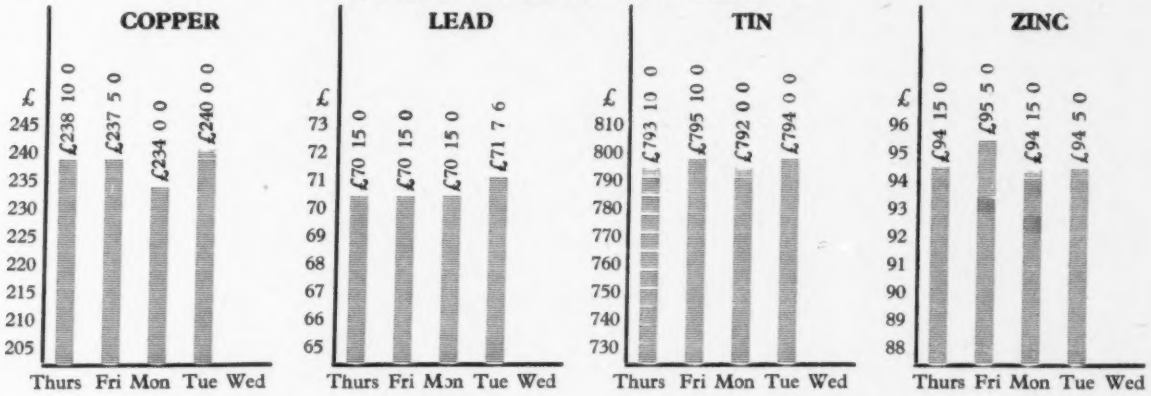
December 10—Institution of Production Engineers. Northern Ireland Region. Kensington Hotel, Belfast. "Extraction and Fabrication of Aluminium." D. H. Abel. 7.30 p.m.

December 10 — Institute of British Foundrymen. Beds. and Herts. Section. K. and L. Steelfounders and Engineers Limited, Letchworth. Liaison meeting with guest members from London. "CO_2 Process." T. C. Wilson. 7.30 p.m.

Non-Ferrous Metal Prices

London Metal Exchange

Thursday 26 November to Tuesday 1 December 1959



Primary Metals

All prices quoted are those available at 2 p.m. 1/12/59

		£	s.	d.
Aluminium Ingots	ton	180	0	0
Antimony 99·6%	„	197	0	0
Antimony Metal 99%	„	190	0	0
Antimony Oxide	„	180	0	0
Antimony Sulphide Lump	„	190	0	0
Antimony Sulphide Black Powder	„	205	0	0
Arsenic	„	400	0	0
Bismuth 99·95%	lb.		16	0
Cadmium 99·9%	„		9	6
Calcium	„	2	0	0
Cerium 99%	„	16	0	0
Chromium	„		6	11
Cobalt	„		14	0
Columbite	per unit		—	
Copper H.C. Electro	ton	240	0	0
Fire Refined 99·70%	„	239	0	0
Fire Refined 99·50%	„	238	0	0

		£	s.	d.
Copper Sulphate	ton	78	10	0
Germanium	grm.		—	
Gold	oz.	12	10	1½
Indium	„		10	0
Iridium	„	24	0	0
Lanthanum	grm.		15	0
Lead English	ton	71	7	6
Magnesium Ingots	lb.		2	0
Notched Bar	„		2	9½
Powder Grade 4	„		6	1
Alloy Ingot, A8 or AZ91	„		2	4
Manganese Metal	ton	245	0	0
Mercury	flask	72	0	0
Molybdenum	lb.	1	10	0
Nickel	ton	600	0	0
F. Shot	lb.		5	5
F. Ingot	„		5	6
Osmium	oz.		nom.	
Osmiridium	„		nom.	

		£	s.	d.
Palladium	oz.	8	0	0
Platinum	„	28	10	0
Rhodium	„	41	0	0
Ruthenium	„	18	0	0
Selenium	lb.		nom.	
Silicon 98%	ton		nom.	
Silver Spot Bars	oz.		6	8¼
Tellurium	lb.		18	0
Tin	ton	794	0	0
***Zinc**				
Electrolytic	ton		—	
Min 99·99%	„		—	
Virgin Min 98%	„	91	17	6
Dust 95/97%	„	126	0	0
Dust 98/99%	„	132	0	0
Granulated 99+%	„	116	17	6
Granulated 99·99+%	„	134	2	6

**Duty and Carriage to customers' works for buyers' account.*

Foreign Quotations

Latest available quotations for non-ferrous metals with approximate sterling equivalents based on current exchange rates

	Belgium fr/kg ≏ £/ton	**Canada** c/lb ≏ £/ton	**France** fr/kg ≏ £/ton	**Italy** lire/kg ≏ £/ton	**Switzerland** fr/kg ≏ £/ton	**United States** c/lb ≏ £/ton
Aluminium		22.50 185 17 6	224 168 0	375 221 5	2.50 212 10	26.80 214 10
Antimony 99.0			230 171 10	450 265 10		29.00 232 0
Cadmium			1,300 975 0			130.00 1,040 0
Copper						
Crude						
Wire bars 99.9				485 286 2 6		
Electrolytic	33.25 244 17 6	30.00 247 17 6	333 249 17 6		3.00 255 0	33.00 264 0
Lead		10.75 88 12 6	103 77 5	166 98 0	.91 77 7 6	13.00 104 0
Magnesium						
Nickel		70.00 578 5	900 675 0	1,200 708 0	7.50 637 10	74.00 592 0
Tin	109.50 806 2 6		1,108 831 0	1,560 919 10	9.75 828 17 6	100.62 805 0
Zinc						
Prime western		12.75 105 7 6				
High grade 99.95		13.35 110 5 0				
High grade 99.99		13.75 113 12 0				
Thermic			130.00 97 10 0			
Electrolytic			138.00 103 10 0	206 121 12 6	1.20 102 0	14.00 112 0

Non-Ferrous Metal Prices (continued)

Ingot Metals

All prices quoted are those available at 2 p.m. 1/12/59

		£	s.	d.
Aluminium Alloy (Virgin)				
B.S. 1490 L.M.5	ton	210	0	0
B.S. 1490 L.M.6	„	202	0	0
B.S. 1490 L.M.7	„	216	0	0
B.S. 1490 L.M.8	„	203	0	0
B.S. 1490 L.M.9	„	203	0	0
B.S. 1490 L.M.10	„	221	0	0
B.S. 1490 L.M.11	„	215	0	0
B.S. 1490 L.M.12	„	223	0	0
B.S. 1490 L.M.13	„	216	0	0
B.S. 1490 L.M.14	„	224	0	0
B.S. 1490 L.M.15	„	210	0	0
B.S. 1490 L.M.16	„	206	0	0
B.S. 1490 L.M.18	„	203	0	0
B.S. 1490 L.M.22	„	210	0	0
Aluminium Alloys (Secondary)				
B.S. 1490 L.M.1	ton	172	0	0
B.S. 1490 L.M.2	„	185	0	0
B.S. 1490 L.M.4	„	192	0	0
B.S. 1490 L.M.6	„	200	0	0
***Aluminium Bronze**				
BSS 1400 AB.1	ton	—		
BSS 1400 AB.2	„	—		

		£	s.	d.
***Brass**				
BSS 1400-B3 65/35	ton	—		
BSS 249	„	—		
BSS 1400-B6 85/15	„	—		
***Gunmetal**				
R.C.H. 3/4%	ton	—		
(85/5/5/5) LG2	„	—		
(86/7/5/2) LG3	„	—		
(88/10/2/1)	„	—		
(88/10/2/½)	„	—		
***Manganese Bronze**				
BSS 1400 HTB1	„	—		
BSS 1400 HTB2	„	—		
BSS 1400 HTB3	„	—		
Nickel Silver				
Casting Quality 12%	„	240	0	0
„ „ 16%	„	245	0	0
„ „ 18%	„	265	0	0
***Phosphor Bronze**				
B.S. 1400 P.B.1. (A.I.D. released)	„	—		
B.S. 1400 L.P.B.1	„	—		

**Average prices for the last week-end.*

		£	s.	d.
Phosphor Copper				
10%	ton	258	0	0
15%	„	260	0	0
Phosphor Tin				
5%	„	—		
Silicon Bronze				
BSS 1400-SB1	„	255	0	0
Solder, soft, BSS 219				
Grade C Tinmans	„	369	10	0
Grade D Plumbers	„	297	0	0
Grade M	„	406	0	0
Solder, Brazing, BSS 1845				
Type 8 (Granulated)	lb.	—		
Type 9	„	—		
Zinc Alloys				
B.S.S.1004 Alloy A	ton	127	7	6
B.S.S.1004 Alloy B	„	131	7	6
Sodium-Zinc	lb.		2	8

Semi-Fabricated Products

Prices vary according to dimensions and quantities. The following are the basis prices for certain specific products.

Aluminium			
Sheet 10 S.W.G.	lb.	2	8½
Sheet 18 S.W.G.	„	2	10½
Sheet 24 S.W.G.	„	3	1½
Strip 10 S.W.G.	„	2	8½
Strip 18 S.W.G.	„	2	9½
Strip 24 S.W.G.	„	2	11
Circles 22 S.W.G.	„	3	2½
Circles 18 S.W.G.	„	3	1½
Circles 12 S.W.G.	„	3	0½
Plate as rolled	„	2	8
Sections	„	3	2
Wire 10 S.W.G.	„	2	11½
Tubes 1 in. o.d. 16 S.W.G.	„	4	1
Aluminium Alloys			
BS1470. HS10W.			
Sheet 10 S.W.G.	„	3	1
Sheet 18 S.W.G.	„	3	3½
Sheet 24 S.W.G.	„	3	11
Strip 10 S.W.G.	„	3	1
Strip 18 S.W.G.	„	3	2½
Strip 24 S.W.G.	„	3	10½
BS1477. HP30M.			
Plate as rolled	„	2	11
BS1470. HC15WP.			
Sheet 10 S.W.G.	„	3	9½
Sheet 18 S.W.G.	„	4	2
Sheet 24 S.W.G.	„	5	0½
Strip 10 S.W.G.	„	3	10½
Strip 18 S.W.G.	„	4	2
Strip 24 S.W.G.	„	4	9½
BS1477. HPC15WP.			
Plate heat treated	„	6	3½
BS1475. HG10W.			
Wire 10 S.W.G.	„	3	10½
BS1471. HT10WP.			
Tubes 1 in. o.d. 16 S.W.G.	„	5	0½
BS1476. HE10WP.			
Sections	„	3	1½
Brass			
Tubes	„	1	11½
Brazed Tubes	„	3	1½
Drawn Strip Sections	„	3	1½
Sheet	ton	210	15 0
Strip	„	210	15 0
Extruded Bar	lb.	2	1½
Extruded Bar (Pure Metal Basis)	„	—	

Brass			
Condenser Plate (Yellow Metal)	ton	197	0 0
Condenser Plate (Naval Brass)	„	209	0 0
Wire	lb.	2	8½
Beryllium Copper			
Strip	„	1	4 11
Rod	„	1	1 6
Wire	„	1	4 9
Copper			
Tubes	lb.	2	4
Sheet	ton	270	0 0
Strip	„	270	0 0
Plain Plates	„	—	
Locomotive Rods	„	—	
H.C. Wire	„	288	5 0
Cupro Nickel			
Tubes 70/30	lb.	3	7½

Lead			
Pipes (London)	ton	111	10 0
Sheet (London)	„	109	5 0
Tellurium Lead	„	£6 extra	
Nickel Silver			
Sheet and Strip 7%	lb.	3	10½
Wire 10%	„	4	5½
Phosphor Bronze			
Wire	„	4	1½
Titanium (1,000 lb. lots)			
Billet 4½" to 18" dia.	lb.	54/-	55/-
Rod ½" to 4" dia.	„	95/-	62/-
Wire ·036"-·232" dia.	„	167/-	110/-
Strip ·003" to ·048"	„	200/-	75/-
Sheet 8'×2'. 20 gauge	„	85/-	
Tube, representative average gauge	„	300/-	
Extrusions	„	105/-	
Zinc			
Sheet	ton	130	15 0
Strip	„	nom.	

Scrap Metal Prices

Merchants' average buying prices delivered, per ton, 1/12/59.

	£
Aluminium	
New Cuttings	151
Old Rolled	135
Segregated Turnings	108
Brass	
Cuttings	166
Rod Ends	153
Heavy Yellow	126
Light	120
Rolled	156
Collected Scrap	121
Turnings	146
Copper	
Wire	214
Firebox, cut up	201
Heavy	196
Light	191
Cuttings	214
Turnings	191
Braziery	162

	£
Gunmetal	
Gear Wheels	176
Admiralty	176
Commercial	163
Turnings	158
Lead	
Scrap	61
Nickel	
Cuttings	—
Anodes	550
Phosphor Bronze	
Scrap	163
Turnings	158
Zinc	
Remelted	86
Cuttings	73
Old Zinc	53

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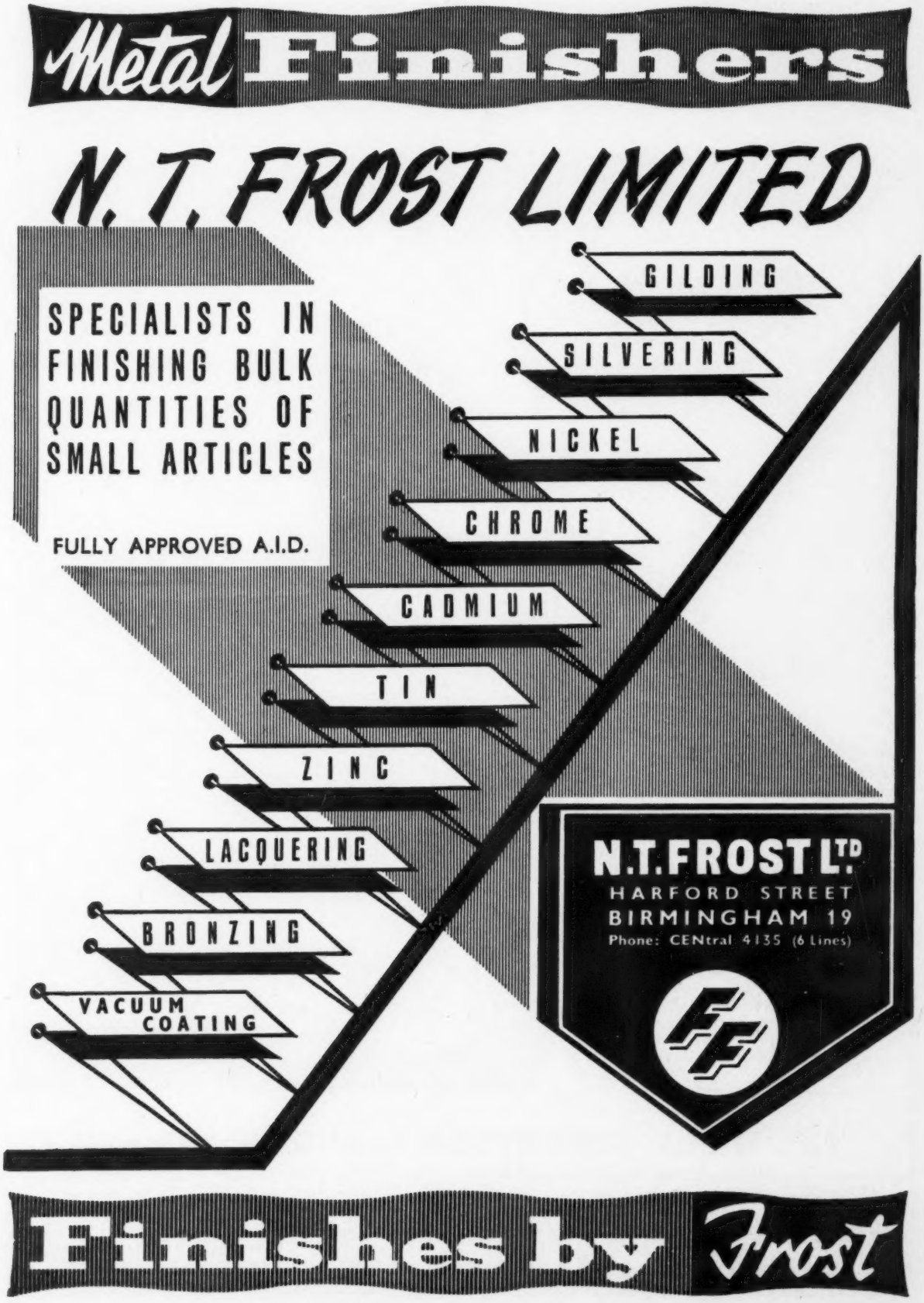
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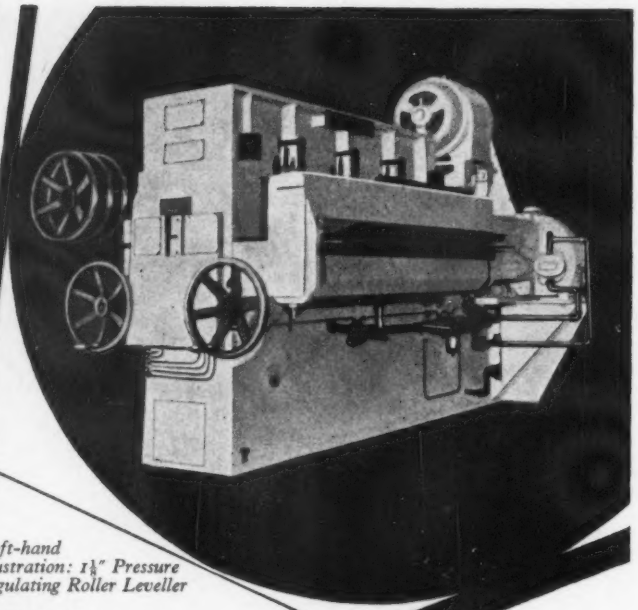
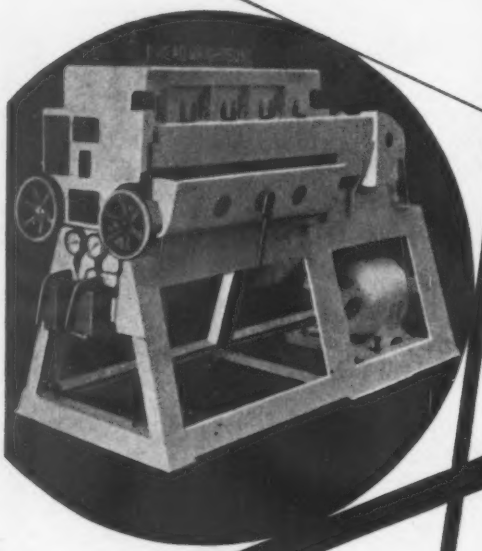
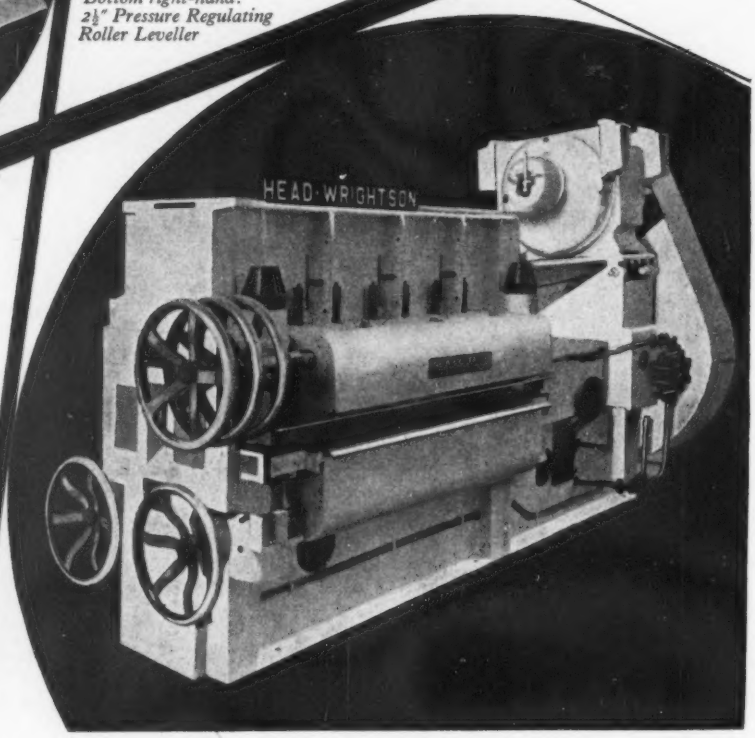




Left-hand illustration: 1½" Pressure Regulating Roller Leveller

Top right-hand: 1¾" Processor Leveller

Bottom right-hand: 2½" Pressure Regulating Roller Leveller



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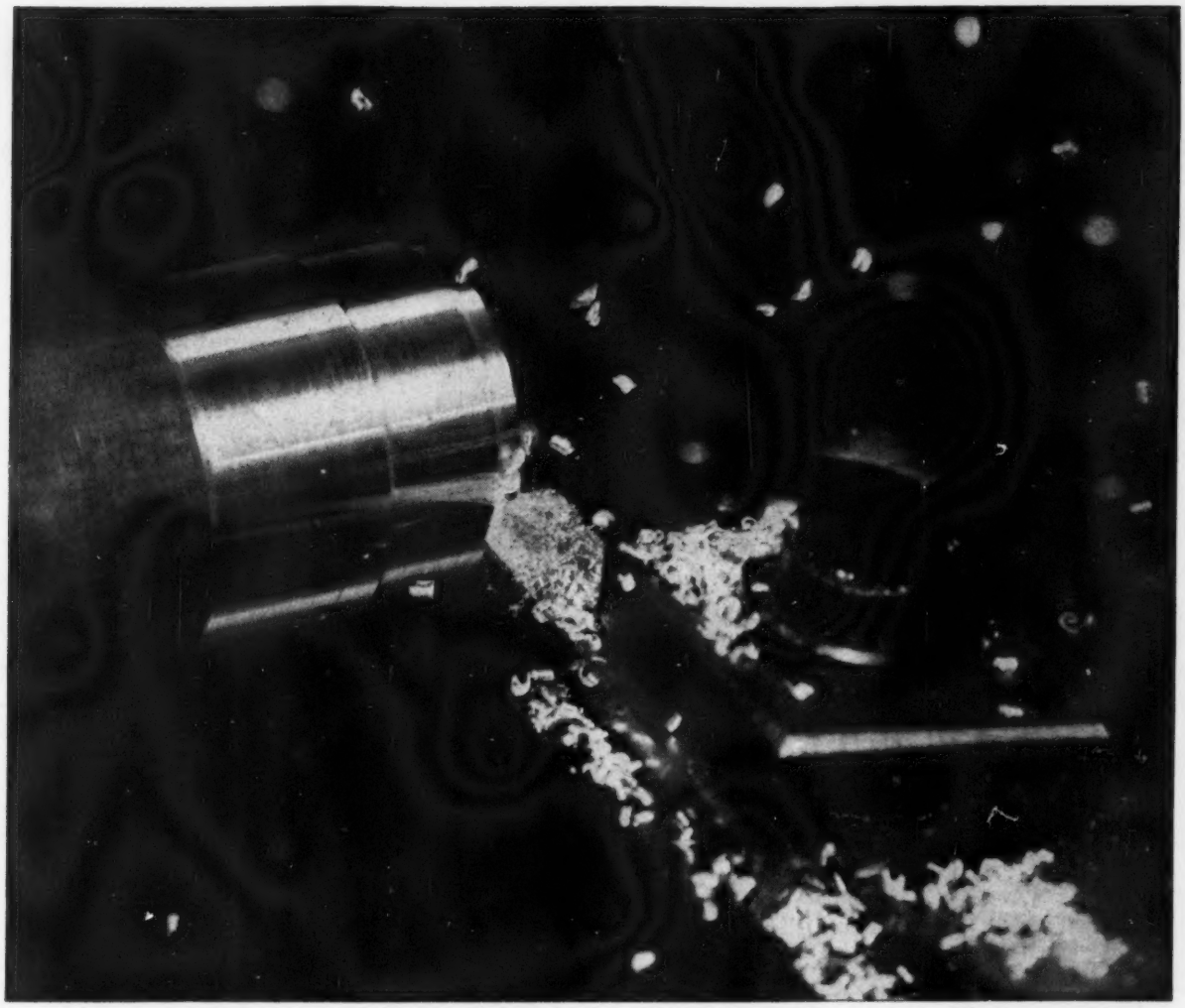

Headstock speed 610 r.p.m., Traverse .005 in. per rev., Depth of cut .05 in. using tool with no rake. Photo taken with high speed electronic flash at 1/5000 sec. and f.16.

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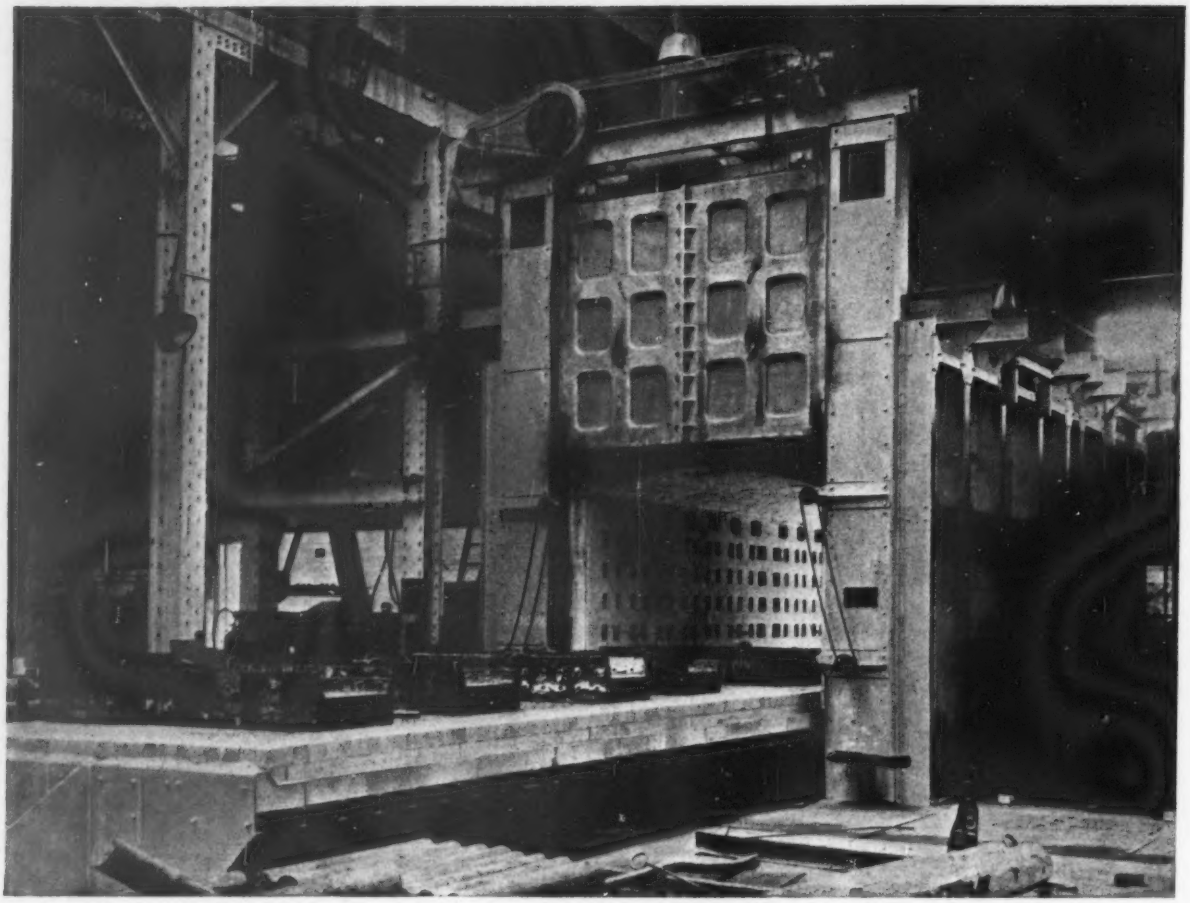

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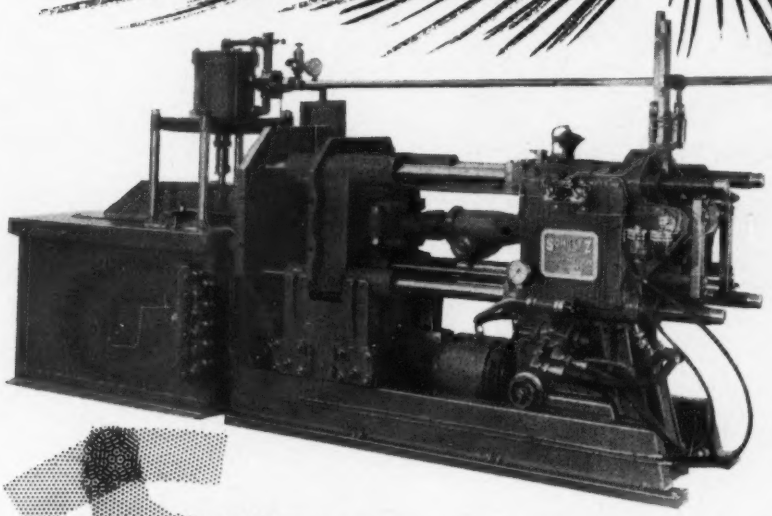

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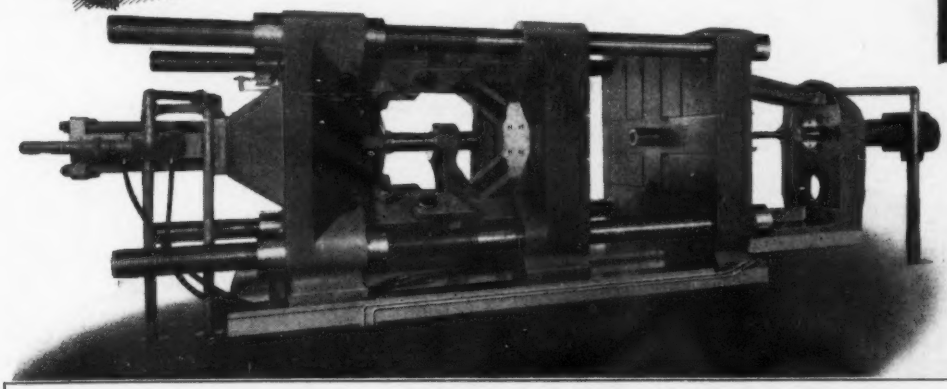

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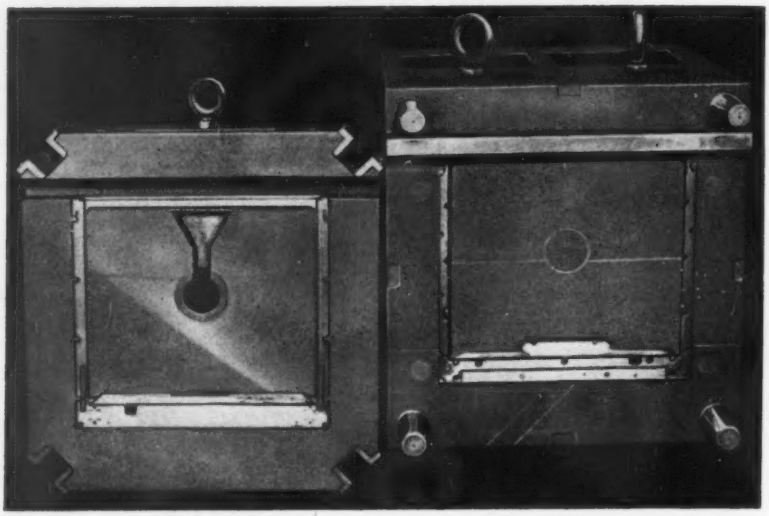

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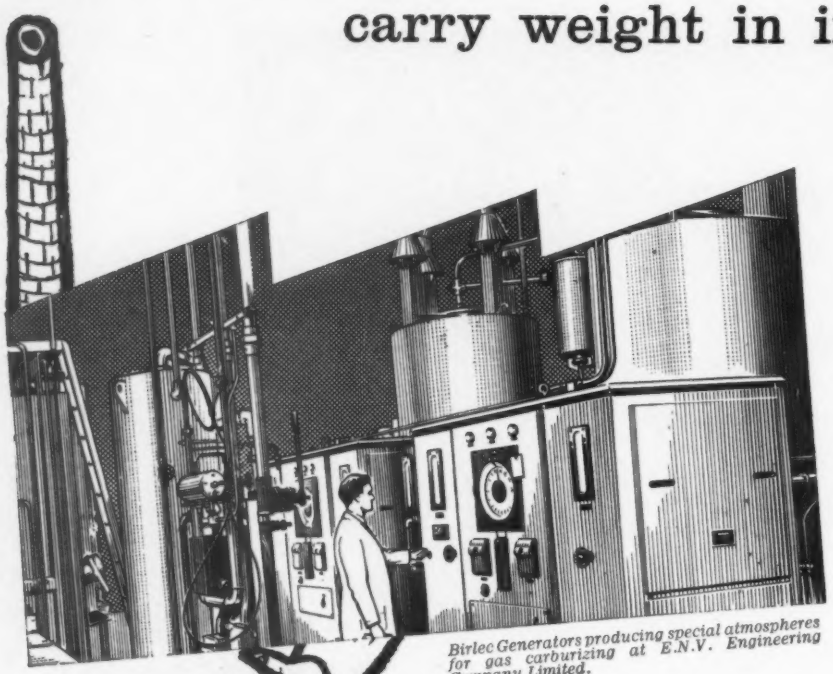

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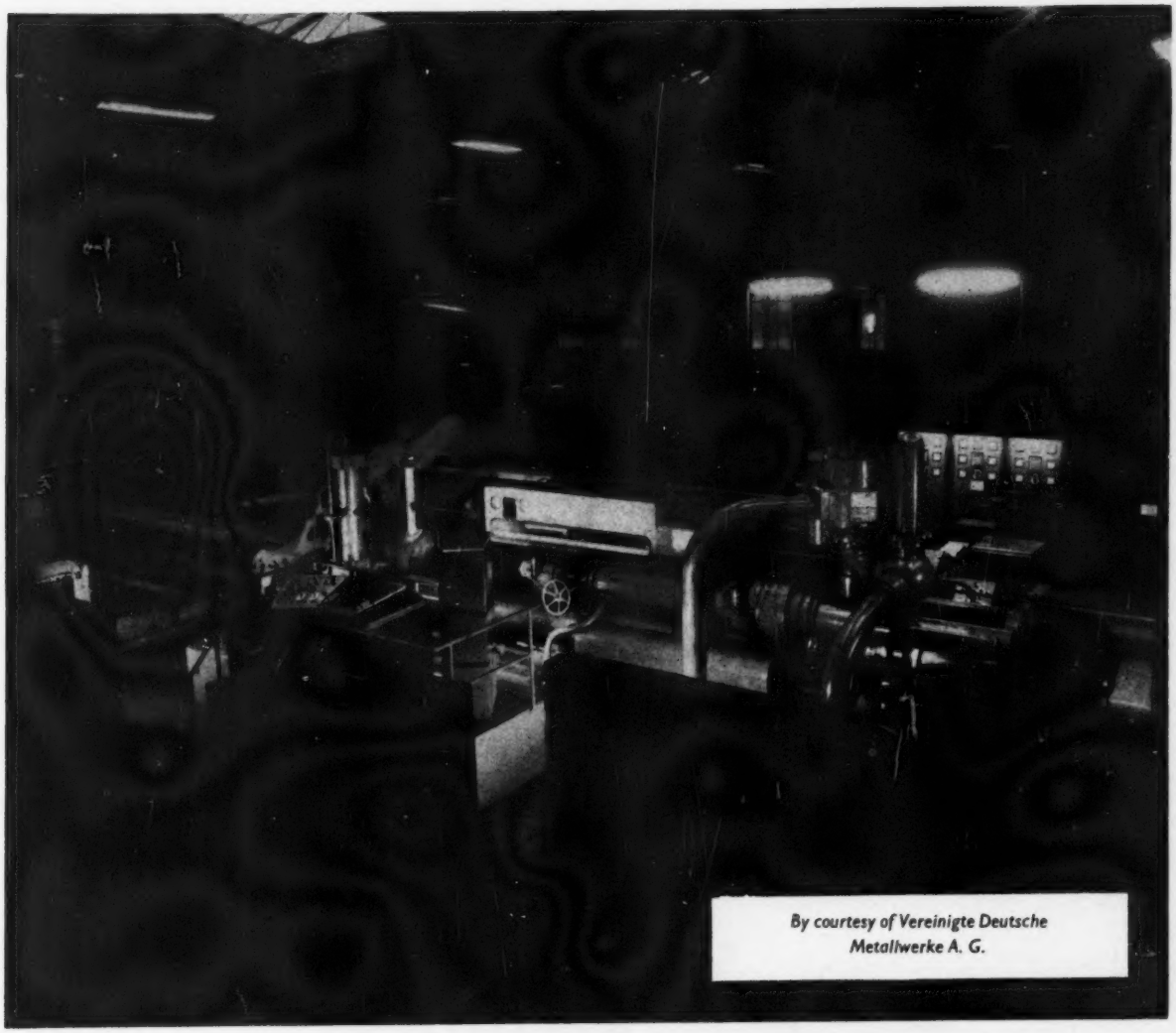

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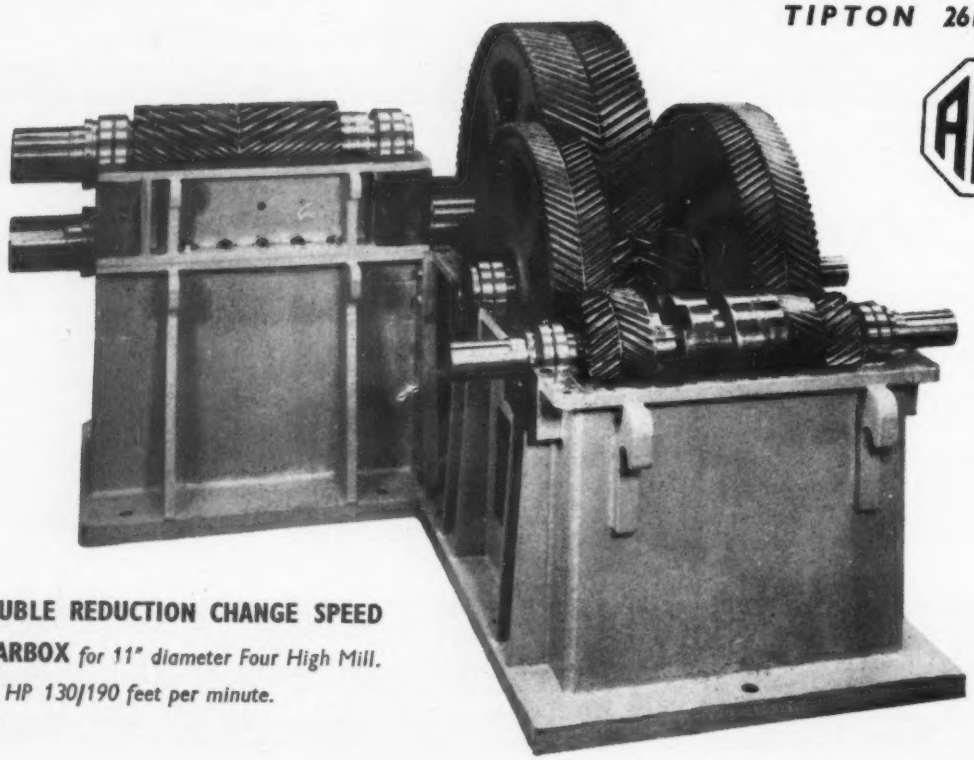

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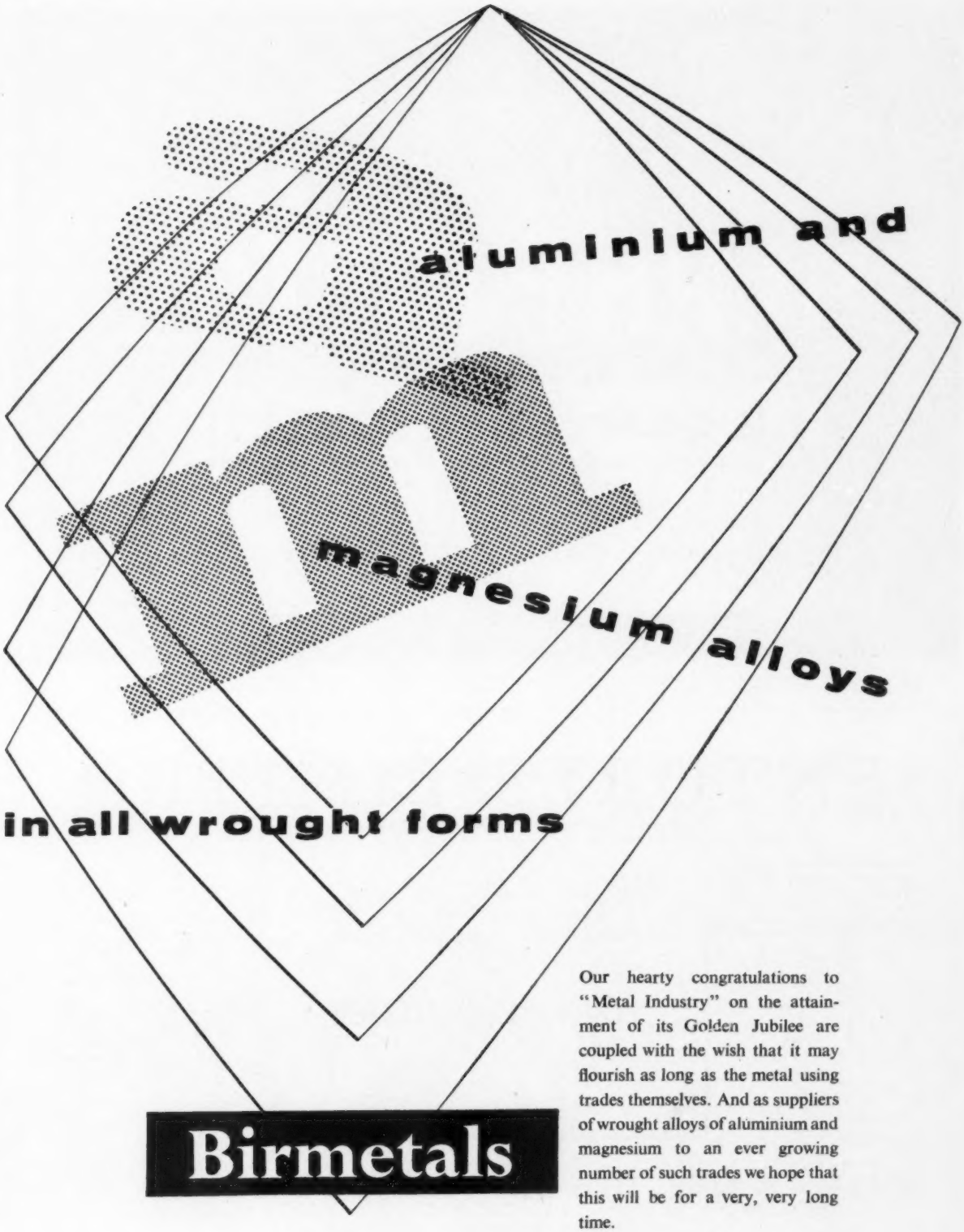

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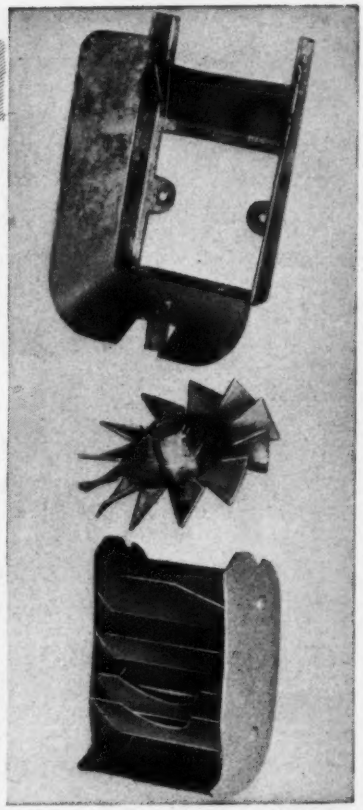

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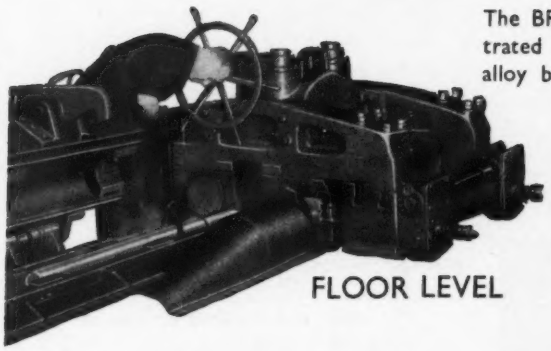

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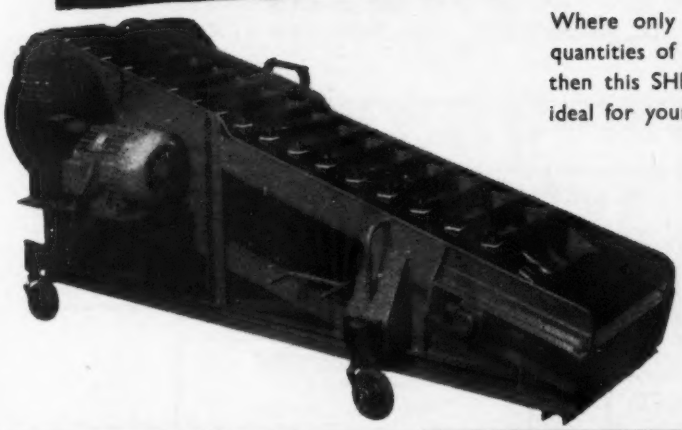

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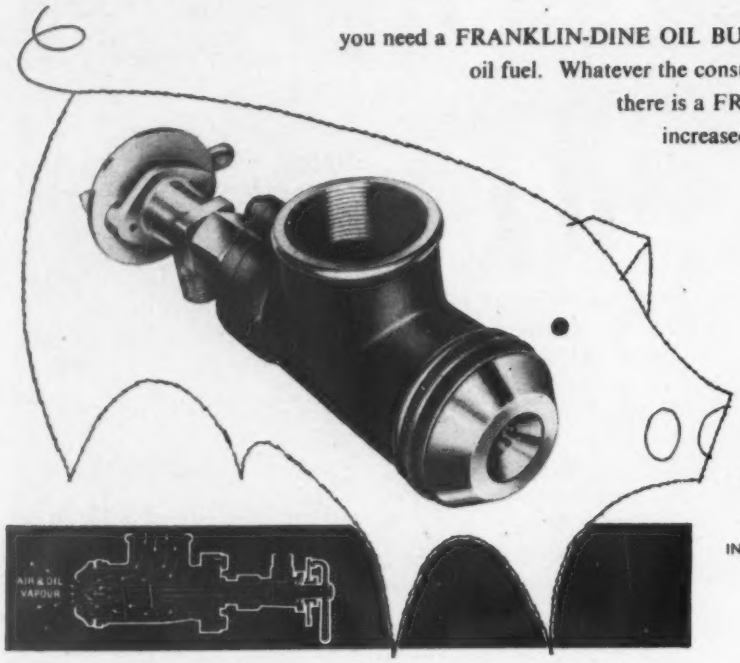

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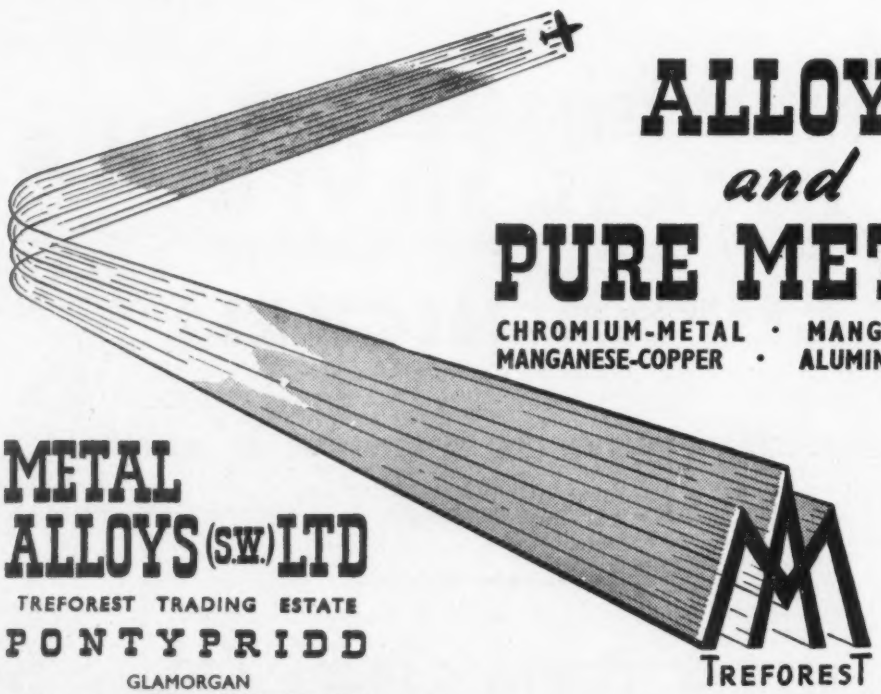

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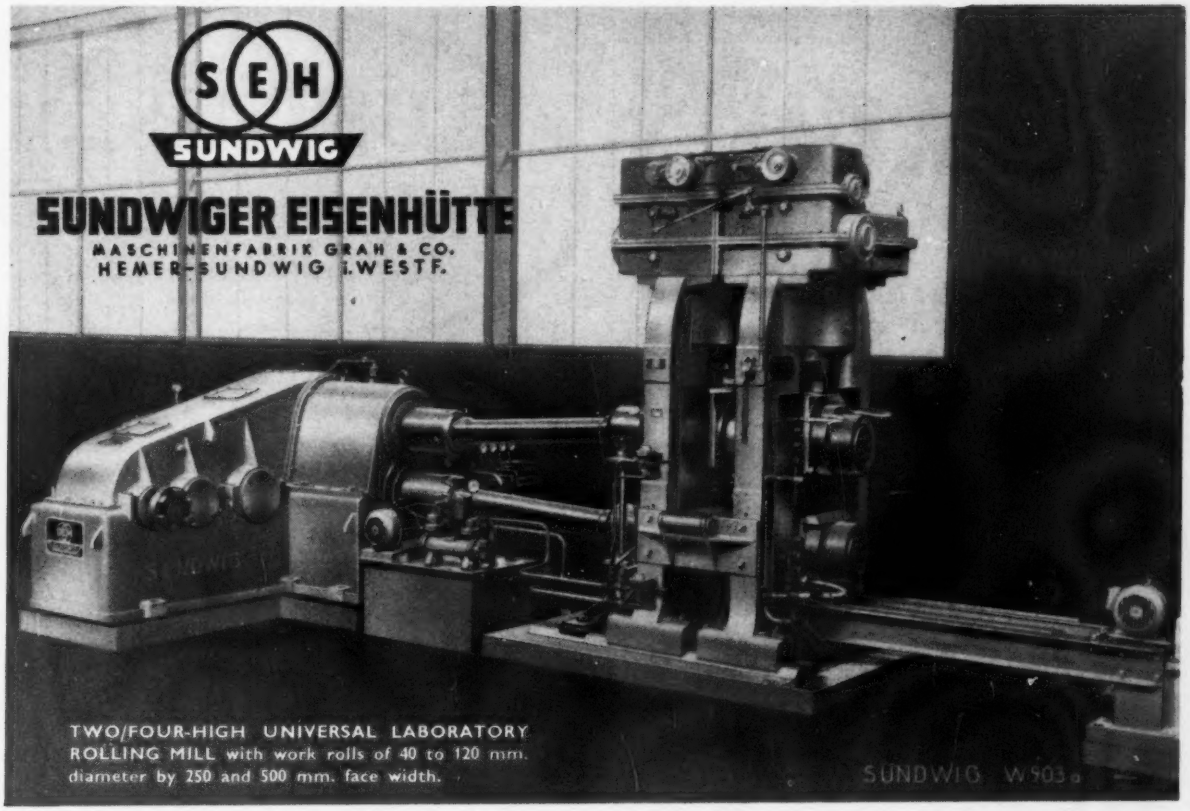
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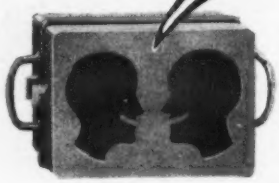

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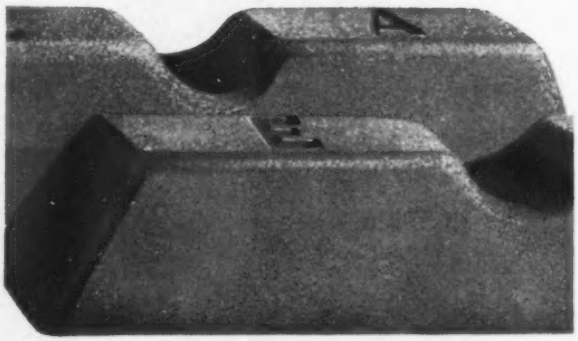

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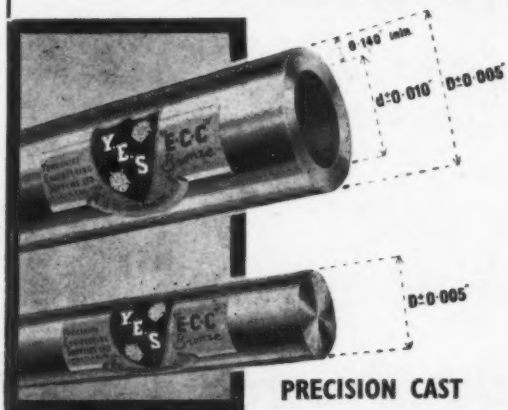

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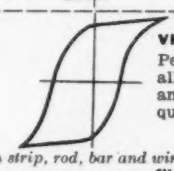

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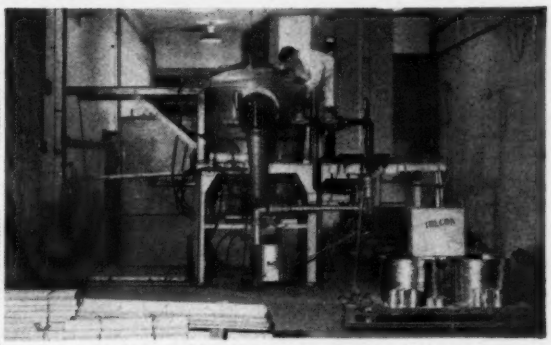

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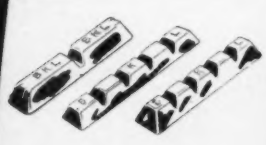

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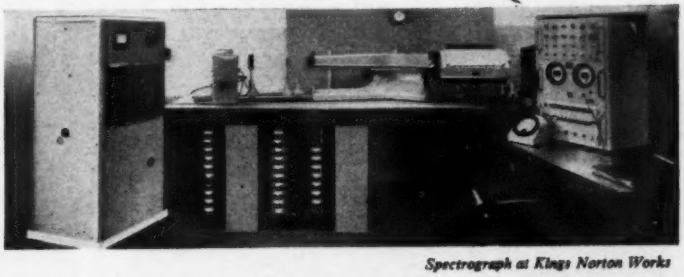

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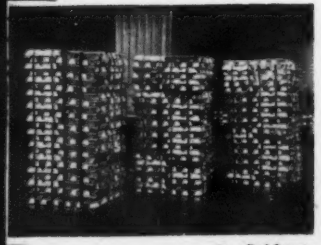

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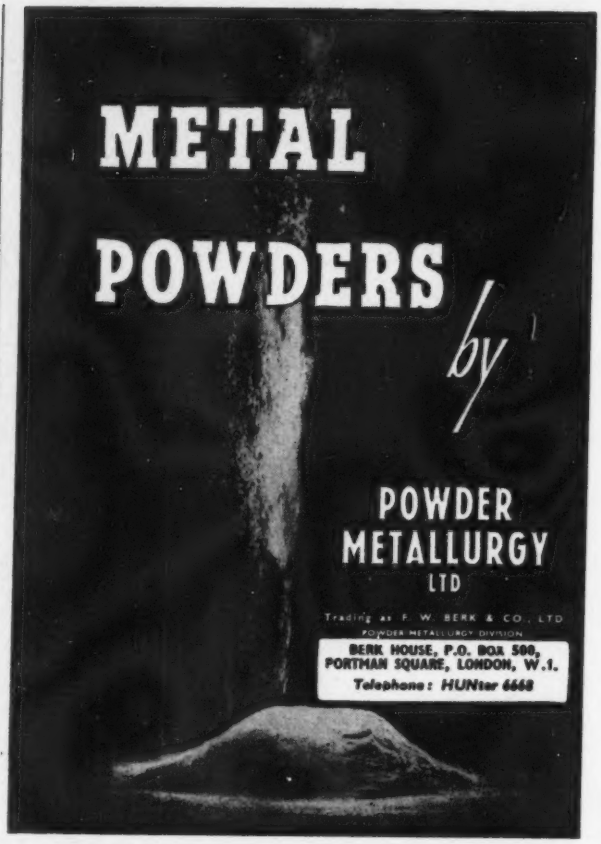

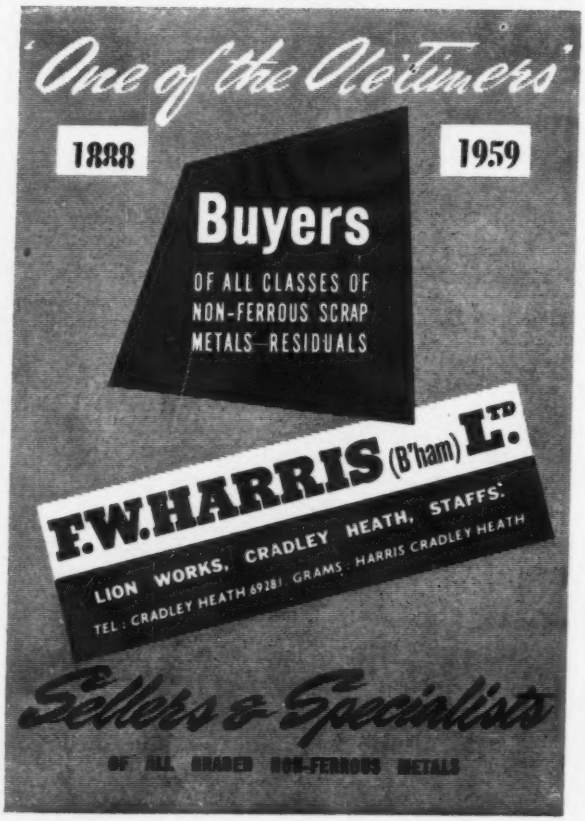

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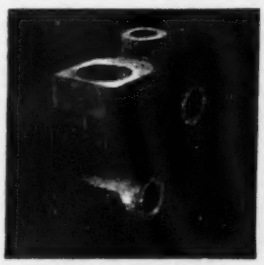

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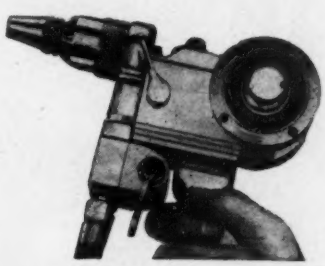

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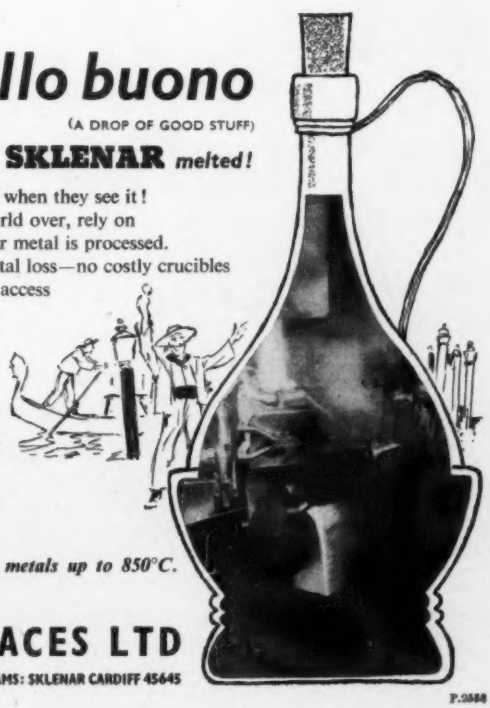

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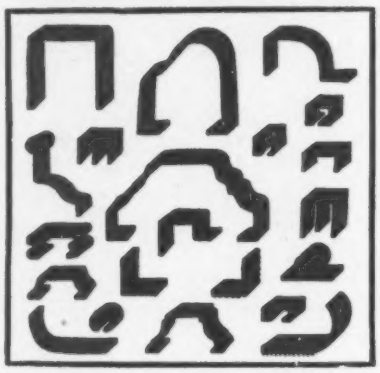

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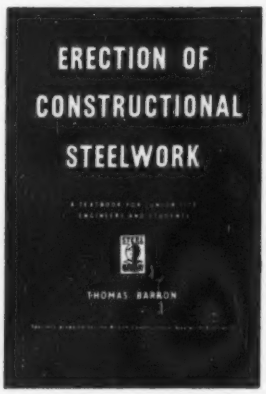

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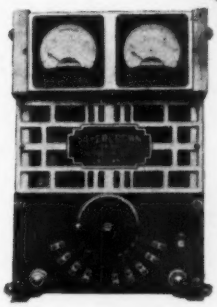

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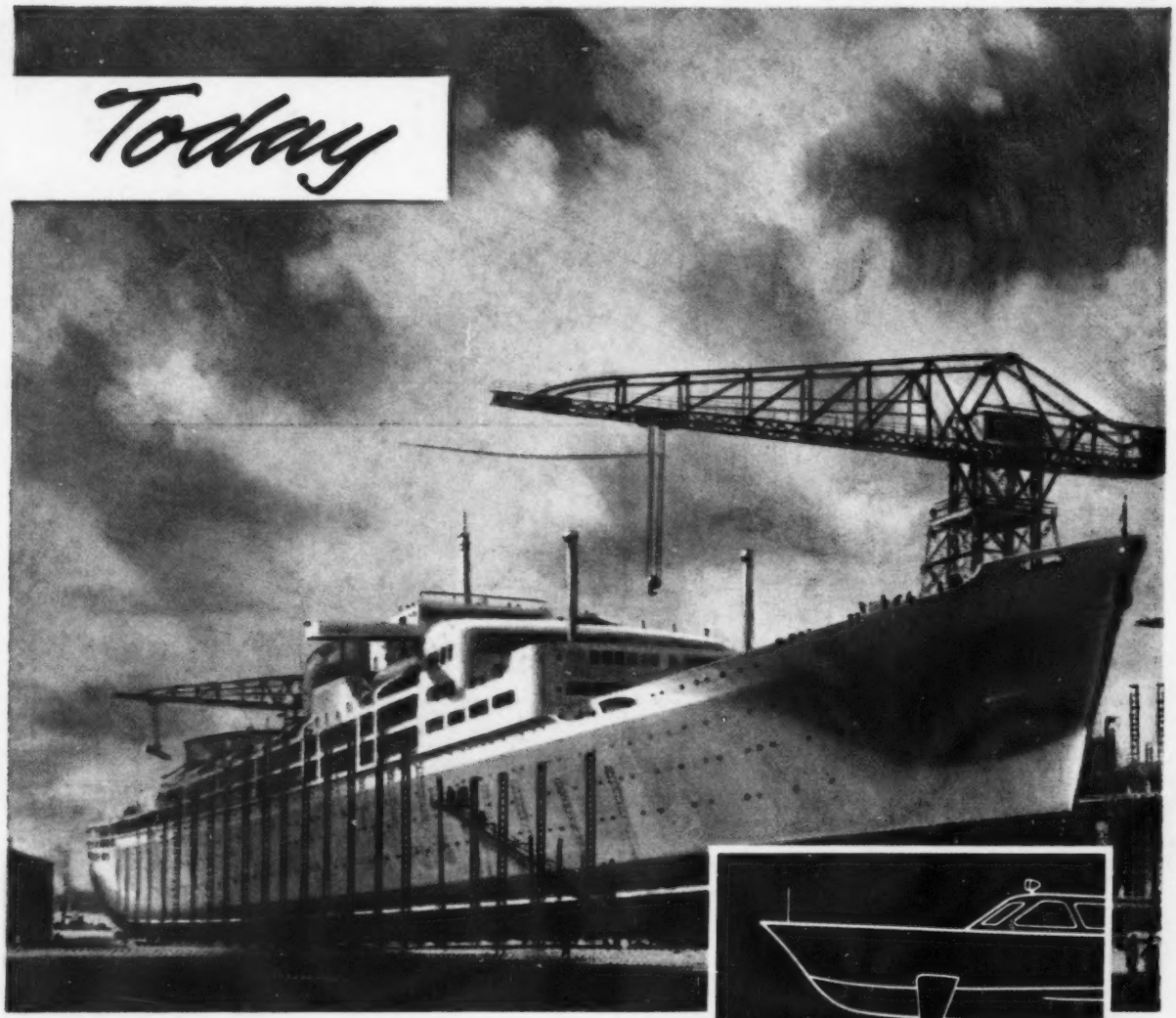

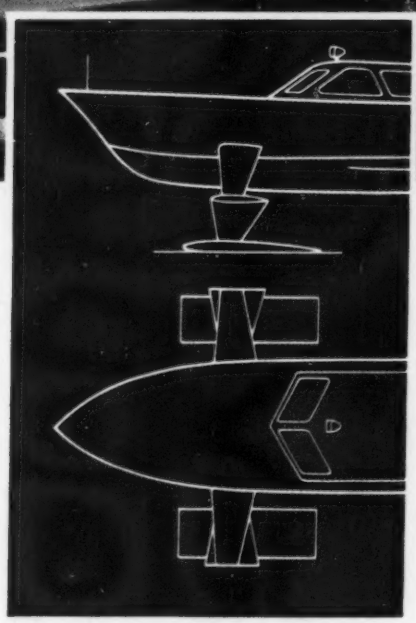

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